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**ESTIMATION OF THE NEW KEYNESIAN PHILLIPS CURVES
FOR THE BALTIC STATES**

Master's thesis

Programme TAAM, specialization Economic analysis

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Tallinn 2021

I hereby declare that I have compiled the thesis independently and all works, important standpoints and data by other authors have been properly referenced and the same paper has not been previously presented for grading. The document length is 17049 words from the introduction to the end of conclusion.

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ABSTRACT

Theoretically grounded New Keynesian Phillips Curve (NKPC) emerged in the 1980s as an alternative to the traditional Phillips curve, which main downside was the lack of the theoretical foundation. Nevertheless, empirical validity of the NKPC is not unambiguous.

The aim of this thesis is to estimate NKPC models for the Baltic states that would be in line with the NKPC theory. Because previous research on the NKPC in the Baltic region is dated, contribution of the thesis is in the application of recent data. Furthermore, recent issue of potential flattening of the NKPC is studied in the thesis.

To account for the endogeneity, instrumental variable estimation methods are used in the thesis. Two-Stage Least Squares method is used as the baseline. The estimation results for the basic closed economy NKPC models are theoretically consistent for all the Baltic states when survey expectations are used as the proxy for the inflation expectations. Out of marginal cost proxies, best results are achieved when either output gap or unemployment gap is used. Comparison of the estimation results for the two subsamples suggests that for Latvia and Lithuania slope of the NKPC has become flatter after the financial crisis of 2008. For Estonia, however, evidence of steeper NKPC slope is found.

The estimation results for the open economy and hybrid specifications of the NKPC are generally theoretically inconsistent. However, external factors are found to be correctly signed and statistically significant for most countries.

To conclude, aim of the thesis is achieved. Estimation results for closed economy models are in line with the NKPC theory. However, these results might be detached from reality, as it would be unrealistic to assume Baltic states to be closed economies. Hence, further research is required.

Keywords: New Keynesian Phillips curve, inflation rate, inflation expectations.

INTRODUCTION

Negative empirical relationship between inflation and unemployment known as the Phillips curve dates back to 1958, when it was documented by Phillips (1958). However, Phillips curve had a major downside of having no theoretical foundation. This was one of the reasons that led to traditional Phillips curve becoming unsuitable to explain inflation dynamics. As an alternative, theoretically grounded Phillips curve, known as The New Keynesian Phillips Curve (NKPC) emerged in the 1980s. NKPC quickly gained popularity and became widely used by the central banks to describe and forecast inflation dynamics. (Mavroeidis *et al.* 2014)

Theoretical microeconomic foundation to the NKPC assumes that economy consists of monopolistically competitive firms and households, who maximize their profits or utility. As a result, their interactions yield the NKPC, which states that inflation rate in the current period is positively affected by the changes in the marginal cost and firms' inflation expectations. (Walsh 2010)

Despite having a theoretical foundation, empirical estimation results for the NKPC models are not unambiguous. One of the reasons might be the fact that marginal costs and inflation expectations cannot be easily measured. Hence, proxy variables are used. However, choice of the proxy variables affects the estimation results. Furthermore, basic NKPC models were extended by various authors. For example, some authors have included the lagged inflation rate to account for the inflation persistence (see Galí and Gertler 1999). External factors were also added into the models to make the economy open (see Galí and Monacelli 2005). Therefore, NKPC estimation results might also depend on the model specification.

Another factor potentially affecting the empirical validity of the NKPC models is the outcome of the financial crisis of 2008. After the crisis, inflation appears to have become more persistent, which suggests that relationship between inflation and marginal costs might have become weaker. (see Bulligan and Vivano 2017; Abbas *et al.* 2016) To conclude, research problem of the thesis lies in the fact that correspondence of empirically estimated NKPC models to theory is not

unambiguous. The importance of the NKPC research lies in its implications for the monetary policy. Empirically consistent NKPC models would help explain what factors affect the inflation rate, as well as how costly is the trade-off between the inflation and economic activity.

The aim of the thesis is to estimate NKPC models for the Baltic states that would be in line with the NKPC theory. To achieve stated aim, three hypotheses, based on the previous empirical literature, are proposed:

1. For the Baltic states, marginal costs have lower impact on the inflation rate after the financial crisis of 2008;
2. For the Baltic states, forward-looking inflation expectations have higher impact on the inflation rate compared to the backwards-looking inflation expectations;
3. For the Baltic states, external factors are in line with the small open economy NKPC theory.

Because previous research on the NKPC models for the Baltic states is dated (see Mihailov *et al.* 2011a; Vašíček 2010; Dabušinskas and Kulikov 2007), contribution of the thesis to the NKPC literature is in the usage of the recent data for the Baltic states. Furthermore, different samples are used to account for potential flattening of the NKPC. Potential flattening of the NKPC was not considered in the earlier literature for the region.

In the empirical analysis, data for the Baltic states is used. The data covers the time period from 2002Q2 to 2019Q4. Choice of time period is motivated by the data availability. However, year 2020 is excluded due to the beginning of the coronavirus pandemic, which might have affected chosen variables. Furthermore, estimations are done on two separate sample periods to account for the structural break. Sample one spans from 2002Q2 to 2010Q4 and includes the financial crisis of 2008. Sample two spans from 2010Q4 to 2019Q4 and reflects the more stable, postcrisis period.

The inflation rate, sourced from Eurostat, is used as the dependent variable in all the models. Three variables are considered as the marginal costs proxies: output gap, labor share gap, and unemployment gap, all of which are sourced from the Eurostat. Two variables are considered as inflation expectations proxies. First is the leaded inflation rate. Second is the survey inflation expectations, which is calculated based on the European Commission Business and Consumer survey results following Dias *et al.* (2010). Moreover, two external factor proxies are used. First

is the change in the real effective exchange rate, sourced from the Eurostat. Second is the change in the commodity price index, sourced from the International Monetary Fund database.

In line with the previous empirical literature, Generalized Method of Moments (GMM) is used for the estimation. For the baseline models special case of GMM, which is the Two-Stage Least Squares (2SLS), is used. As a robustness check heteroscedasticity and autocorrelation consistent (HAC) GMM with continuously updated estimator (CUE) is used. Usage of CUE GMM as a robustness check is motivated by its partial robustness to weak instruments (see Zobl and Ertl 2020).

The thesis consists of three main chapters, each of which is divided into several sections, and in some cases subsections. Chapter 1 of the thesis provides a brief overview of the Phillips curve historical background and development. Same chapter also provides a detailed derivation of the NKPC. Chapter 1 concludes with the discussion of previous empirical literature.

Chapter 2 of the thesis provides an overview of data and methods used. Same chapter also provides an intuition for the parameter signs and values required to be consistent with the NKPC theory. Chapter 2 provides descriptive statistics, and data stationarity testing results as well as description of the estimation methods.

Chapter 3 of the thesis is dedicated to the estimation results. Firstly, basic closed economy models are analyzed through the application of different combinations of proxies. Models are further studied through different model specifications. Chapter 3 concludes with the discussion of results.

Thesis author would like to thank Rachatar Nilavongse for the provided feedback on the theoretical aspects of the thesis. Thesis author would also like to thank Avo Org for proofreading the summary in Estonian language (*kokkuvõtte*).

1. OVERVIEW OF THE NEW KEYNESIAN PHILLIPS CURVE

1.1. Historical background and development of the Phillips curve

Negative relationship between inflation and unemployment known as the Phillips curve originated from Phillips's (1958) article. However, evidence of an empirical relationship between inflation and employment dates back to Fisher (1926).

Fisher (1926) presented a strong positive correlation between inflation and employment for the United States data from 1915 to 1925. Fisher (1926) proposed that because of inflation firm's income increases faster than its expenses. This happens because some expenses, such as loans and wages, might be fixed by a contract. Higher profit stimulates the economy leading to higher employment. Therefore, Fisher (1926) proposed that employment is caused by inflation.

Thirty-two years after Fisher (1926), Phillips (1958) has presented a negative empirical relationship between wage inflation and unemployment for the United Kingdom data from 1861 to 1957 (see Figure 1). Phillips hypothesized that wage inflation is caused by unemployment through the mechanism of demand and supply. Low unemployment rate implies low labor supply. As a result, firms would pay higher wages to attract employees. In the opposite case, firms would have less incentive to increase wages as labor supply is high.

As seen from the Figure 1, according to Phillips (1958) estimation, relationship between wage inflation and unemployment is non-linear. This is because even at high unemployment rate people would be unwilling to accept wages lower than the prevailing rate. Hence, at high unemployment wage inflation rate decreases slower.

Phillips (1958) and Fisher (1926) had different conclusions regarding the direction of the causality. However, their results can be generalized by stating that there was a positive empirical relationship between economic activity and inflation in the beginning of the 20th century for both the United States and the United Kingdom.

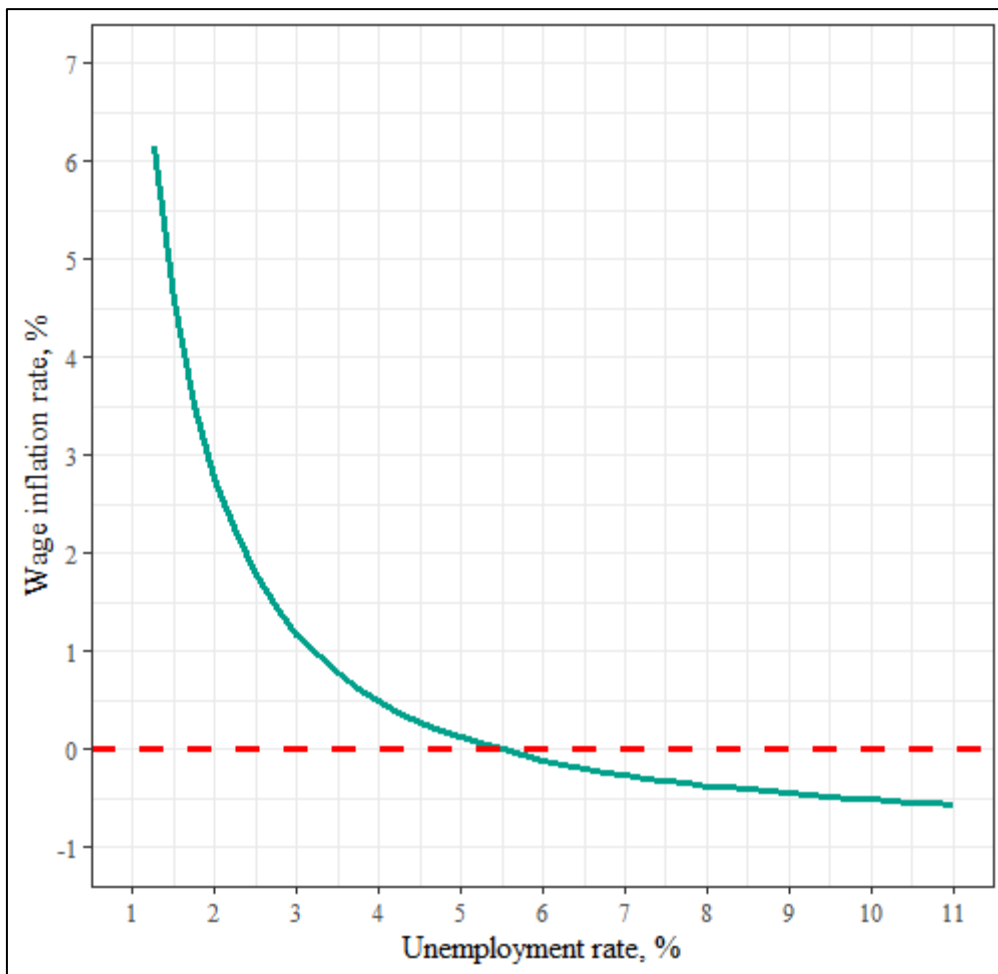


Figure 1. Traditional basic Phillips curve estimated with the United Kingdom data

Source: author's example based on Phillips (1958)

Note: red dashed line represents the zero axis

Both articles also had a similar downside in lack of theoretical basis. Explanations of described empirical relationships were the respective author's speculations. According to Sleeman (2011) Phillips himself was reluctant to publish the article, considering his research on the topic to be just an empirical exercise.

While Phillips (1958) and Fisher (1926) presented similar ideas, Phillips's (1958) article had higher impact. Gordon (2011) proposed two reasons for this outcome. First, Phillips's (1958) article was published when preexisting theory regarding inflation dynamics in the United States was failing to describe rising inflation in the 1950s. Second, Samuelson and Solow (1960) brought further attention to the Phillips (1958) article by applying his findings to the United States and giving results a policy context. Samuelson and Solow (1960) presented Phillips curve for the United States as a short-run trade-off between inflation and unemployment. Taken

together, these two factors contributed to Phillips curve becoming a policy instrument during the early 1960s in the United States.

The validity of the Phillips curve as a trade-off between inflation and unemployment came into question, as inflation kept accelerating during the period of 1963-1969 (Gordon 2011). The reason for accelerating inflation was proposed by Friedman (1968) and was related to the inflation expectations. As a result, expectations augmented Phillips curve was developed. Phillips (1958) assumed agent's expectations of nominal prices to be fixed. Friedman (1968) on contrary, suggested that changes in prices would affect inflation expectations. Friedman (1968) proposed a theoretical hypothesis of the natural rate of unemployment, which is the rate of unemployment at which there would be no pressure on the real wage¹.

Gordon (2011) framed the natural rate hypothesis in terms of the Phillips curve as follows. Targeting an unemployment rate lower than the natural rate would at first decrease unemployment and increase inflation². However, as prices begin to increase agents would adjust their inflation expectations. This would in turn shift the Phillips curve to the right. As a result, unemployment would return to the initial level, but inflation would now be higher. If policymakers continue pursuing the unemployment target that is lower than the natural rate, same cycle will repeat. This means that to maintain an unemployment rate level lower than the natural rate, inflation would have to keep rising indefinitely. In case of unemployment target being higher than the natural rate same mechanism would apply, leading to accelerating deflation. Potential shift of the Phillips curve was also acknowledged by Samuelson and Solow (1960). However, they have linked the potential shift of the Phillips curve to the long-run policy changes rather than the expectations.

Only option left for policymakers would be to target the natural rate itself. However, Friedman (1968) explained that targeting the natural rate of unemployment might be impossible, because the natural rate will change over time. Hence, Friedman (1968) proposed that policy focus should be not on the natural rate targeting, but instead on counteracting the shocks that lead to deviations from the natural rate.

¹ Gordon (2011) explained the Friedman's natural rate of unemployment as the rate of unemployment at which agent's inflation expectations would be accurate.

² This is the movement along the Phillips curve (see Figure 1).

Parallel to Friedman (1968), Phelps (1967) has highlighted the importance of the inflation expectations. Phelps (1967) proposed a theoretical model with equilibrium unemployment, which is the level of unemployment at which inflation expectations would equal actual inflation. Similarly, to the natural rate hypothesis, deviation from equilibrium unemployment would lead to accelerating inflation or deflation.

The main difference between the theoretical models of Friedman (1968) and Phelps (1967) according to Gordon (2011) was in the assumptions regarding the accuracy of expectations across firms and employees. Friedman (1968) assumed that firms' expectations are always accurate, while employees' expectations are always inaccurate. Phelps (1967) assumed that both firms' and employees' expectations are always inaccurate. Nevertheless, same criticism applies to both theoretical models. Both firms and employees have access to information about the inflation. and would observe changes in prices of goods and services they consume. Hence, it would be problematic to assume that some of the agents always have inaccurate inflation expectations.

The natural rate hypothesis was further developed by Lucas (1973). In his model, Lucas (1973) assumed that suppliers are scattered over many markets where demand is distributed unevenly, which leads to price deviations. Furthermore, based on Muth (1961)³ Lucas assumed that suppliers' expectations are rational.

On one hand, Lucas (1973) addressed the previously mentioned criticism of Friedman (1968) and Phelps (1967). On the other hand, Lucas's (1973) model failed to account for business cycles longer than one time period, which was contrary to the real-life multi-year business cycles. This led to reconsideration of the Phillips curve. As a result, two separate approaches emerged. One was focused on inflation being explained by inertia, demand, and supply. Other led to the emergence of the New Keynesian framework and the New Keynesian Phillips curve. (Gordon 2011)

To conclude, Phillips curve originated from the Phillips (1958) article. Phillips curve seemed to accurately describe inflation dynamics in the early 1960s and was accepted as a short-run policy tradeoff between inflation and unemployment. However, it had such shortcomings as lack of

³ Muth (1961) was first to formalize the idea of rational expectations.

theoretical basis and assumption of fixed inflation expectations. These shortcomings became apparent as inflation rate began to accelerate in the 1960s. To explain accelerating inflation rate, natural rate of unemployment hypothesis was proposed. This hypothesis assumed that if unemployment deviated from its natural rate, inflation or deflation would accelerate. As a result, expectations augmented Phillips curve was developed. However, it failed to account business cycles. As a result, further developments of the Phillips curve split into separate branches. One of those branches was the New Keynesian Phillips curve, which is discussed in the next section.

1.2. New Keynesian micro foundation and Phillips curve derivation

In the 1970s, both inflation and unemployment rates were increasing simultaneously in the United States. This occurrence challenged the prevalent Keynesian macroeconomic framework, which Phillips curve was a part of. (Abbas *et al.* 2016)

As a response to the Keynesian framework failings, New Keynesian framework has emerged. As stated by Gordon (1990) aim of the New Keynesian framework was to give a microeconomic explanation to the price rigidity. Some of the microeconomic sources of price rigidity are, for example, imperfect competition and imperfect information. Galí (2018) described the New Keynesian framework as a mix between the traditional Keynesian economics and the real business cycles theory. Besides previously mentioned price rigidities and market failures, Galí (2018) highlighted that the New Keynesian framework also featured rational expectations.

The New Keynesian Phillips Curve (further referred to as the NKPC) was developed as a part of the New Keynesian macroeconomic framework in the 1980s and quickly gained traction, leading to its widespread use by central banks (Mavroeidis *et al.* 2014). Because of the microeconomic foundation importance, deriving the NKPC would give the most insight into the model. Following descriptions and derivations are based on that of Walsh (2010). Throughout the derivation process, discrete time is used.

Before the NKPC derivation, some general assumptions regarding the New Keynesian model should be stated. The basic New Keynesian model consists of identical monopolistically competitive firms and households. Households supply firms with labor, consume goods and hold money. Firms hire labor and produce differentiated goods. However, not all firms can adjust their

prices each period which creates the nominal price rigidity. Following rational expectations both firms and households behave optimally. Firms maximize expected profits (see equation 1.10) and households maximize expected present value of utility (see equation 1.1).

Following stated assumptions, the NKPC microeconomic foundation can be summarized as follows. Households aim to maximize their expected present value of utility by choosing consumption level, money balances and amount of time spent working. Because households consume different goods, they aim to achieve chosen level of consumption as cheaply as possible. Hence, households form their demand for goods based on the prices. Firms aim to maximize their profits by choosing the amount of labor and the prices of their goods considering the demand by the households and the possibility that their prices might remain fixed. This dynamic process gives a foundation to the NKPC, which describes how inflation rate is positively affected by changes in marginal costs and inflation expectations.

$$E_t \sum_{i=0}^{\infty} \beta^i \left[\frac{C_{t+i}^{1-\sigma}}{1-\sigma} + \frac{\gamma}{1-b} \left(\frac{M_{t+i}}{P_{t+i}} \right)^{(1-b)} - \chi \frac{N_{t+i}^{1+\eta}}{1+\eta} \right], \gamma; \chi > 0 \quad (1.1)$$

where

- β – discount factor,
- C_t – consumption,
- σ, b – coefficients of relative risk aversion (RRA),
- M_t/P_t – real money balances,
- γ – money balance scale parameter,
- N_t – time spent working,
- χ – disutility of labor,
- η – elasticity of labor.

Equation 1.1 shows that expected present value of utility at time t depends positively on future consumption C_{t+i} and future real money balances M_{t+i}/P_{t+i} . Both consumption and real money balances exhibit constant relative risk aversion (CRRA). This means that consumption and real money balances RRA coefficients equal σ and b respectively. Any positive value can be an RRA coefficient. However, in case of RRA coefficient being equal one consumption and money balances would become natural logarithms.

Money balances in the equation 1.1 provide utility by being the source of liquidity. Utility given in the equation 1.1 also depends on the positive discount factor β , that takes value between zero and one.

Because goods produced by firms are differentiated, household's consumption is an aggregation. This leads to equation 1.2 which shows the composition of the household's consumption. Since goods are produced by different firms, subscript j denotes a single firm.

$$C_t = \left[\int_0^1 c_{jt}^{\frac{(\theta-1)}{\theta}} dj \right]^{\frac{\theta}{(\theta-1)}}, \quad \theta > 1 \quad (1.2)$$

where

c_{jt} – good produced by firm j at time t ,

θ – price elasticity of demand.

Because households act optimally, regardless of chosen level of consumption C_t , they would aim to minimize the cost of achieving said consumption level. As a result, households face a minimization problem. Solution to this problem results in the equation 1.3, which is the households' demand for goods produced by firm j .

$$c_{jt} = \left(\frac{p_{jt}}{P_t} \right)^{-\theta} C_t, \quad P_t \equiv \left[\int_0^1 p_{jt}^{1-\theta} dj \right]^{\frac{1}{(1-\theta)}} = \psi_t \quad (1.3)$$

where

p_{jt} – price of the good produced by the firm j at time t ,

P_t – aggregated price index,

ψ_t – Lagrange multiplier⁴.

Demand depends positively on the relative price (p_{jt}/P_t) and consumption C_t . Demand for a good produced by firm j would increase if overall consumption increases or if relative price decreases⁵. Furthermore, as price elasticity of demand θ increases, firms market power decreases. This is because goods become substitutes.

Using aggregate price index given in the equation 1.3 household's budget constraint can be expressed in real terms, which is shown in the equation 1.4.

⁴ Lagrange multiplier ψ_t is carried over from the minimization problem solution.

⁵ Relative price will decrease if aggregate price index P_t increases or if the price of a particular good p_{jt} decreases.

$$C_t + \frac{M_t}{P_t} + \frac{B_t}{P_t} = \left(\frac{W_t}{P_t}\right) N_t + \frac{M_{t-1}}{P_t} + (1 + i_{t-1}) \left(\frac{B_{t-1}}{P_t}\right) + \Pi_t \quad (1.4)$$

where

B_t – bonds held by the households,

W_t – wages received,

i_t – nominal interest rate,

Π_t – real profits.

Equation 1.4 shows that households finance their consumption, acquisition of bonds and holding of real money balances by the right-hand side of the equation. This comprises wages, interest payments on previously acquired bonds, money reserves left over from the previous period and real profits from firms.

Expected present value of utility (1.1) can be maximized by being subject to the real budget constraint (1.4). Solving this maximization problem yields three conditions that are necessary to achieve equilibrium. First of those conditions is the Euler intertemporal consumption condition shown in the equation 1.5.

$$C_t^{-\sigma} = \beta(1 + i_t) E_t \left(\frac{P_t}{P_{t+1}}\right) C_{t+1}^{-\sigma} \quad (1.5)$$

The Euler condition states that gaining one unit of consumption today provides same utility as putting the money in savings and having higher consumption in the future. Next two equations are inter-temporal optimality conditions. First of them is given in the equation 1.6.

$$\frac{\gamma \left(\frac{M_t}{P_t}\right)^{-b}}{C_t^{-\sigma}} = \frac{i_t}{1 + i_t} \quad (1.6)$$

Equation 1.6 shows that marginal rate of substitution between real money reserves and consumption is equal to the opportunity cost of holding money, which is the loss of interest payments. Final condition is given in the equation 1.7.

$$\frac{\chi N_t^\eta}{C_t^{-\sigma}} = \frac{W_t}{P_t} \quad (1.7)$$

Equation 1.7 states that marginal rate of substitution between leisure and consumption equals the real wage. The more time is spent on leisure the less time is spent on work.

After households' maximization problem is solved, next step to derive the NKPC is to set up firm's behavior. Firms aim to maximize profits subject to three constraints, which are:

1. Production function given by the equation 1.8;
2. Demand for goods given by the equation 1.3;
3. Inability to adjust prices every period, which is the Calvo pricing.

In the New Keynesian model firm's production is based on the labor input N_{jt} and aggregate productivity disturbance Z_t . Assumption of $E(Z_t)$ being equal to 1 in the equation 1.8 means constant return to scale⁶.

$$c_{jt} = Z_t N_{jt}, \quad E(Z_t) = 1 \tag{1.8}$$

where

Z_t – aggregate productivity disturbance.

Firms face 'dual optimization problem' as they aim to minimize the costs and maximize the profits. First, costs minimization of the wage bill $W_t N_{jt}$ subject to the production function (1.8) is shown. Solution to firms cost minimization problem yields equation 1.9.

$$\varphi_{jt} = \frac{W_t/P_t}{Z_t} \tag{1.9}$$

where

φ_{jt} – real marginal cost of good produced by the firm j .

Equation 1.9 shows that real marginal cost depends on the real wage W_t/P_t and aggregate productivity disturbance Z_t . Fall in productivity or decrease of aggregate price level P_t would lead to higher marginal cost. Increase in nominal wage would also lead to higher marginal cost. As was shown in the production function (see equation 1.8) firms only use labor as input for production. As a result, marginal cost in this model represents increase in cost that arises when

⁶ One additional unit of labor input would yield one additional unit of good.

one additional good c_{jt} is produced. Because constant return to scale was assumed firms' marginal cost is constant.

To maximize the profit, firms pick optimal price, accounting for the possibility that price might remain fixed for some time. To describe the price rigidity Calvo pricing model is used, which states that each period there is a fraction of firms ω that do not adjust their prices and fraction of firms $(1 - \omega)$ that do. While probability ω itself is constant, firms are chosen randomly each period. To set optimal price p_{jt} firms maximize the function given in the equation 1.10 subject to the households' demand (equation 1.3).

$$E_t \sum_{i=0}^{\infty} \omega^i \Delta_{i,t+i} \left[\left(\frac{p_{jt}}{P_{t+i}} \right) c_{jt+i} - \varphi_{jt+i} c_{jt+i} \right], \quad \Delta_{i,t+i} = \beta^i \left(\frac{C_{t+i}}{C_t} \right)^{-\sigma}, \quad 0 < \omega < 1 \quad (1.10)$$

where

$\Delta_{i,t+i}$ – discount factor,

ω – probability that firm does not adjust its price.

Function 1.10 shows that firms maximize expected discounted profit. Expected profit is given as the difference between expected revenue from selling goods and expected cost of producing said goods. Higher price affects profit through the lower demand in line with equation 1.3. Discount factor given by $\Delta_{i,t+i}$ states that general demand in the economy is downward sloping. Hence, firms must also account for the general demand when choosing the optimal price. Following the definition of $\Delta_{i,t+i}$, firms expected profit also depends on the discount factor β .

Inserting (1.3) into (1.10) to replace the c_{jt+i} term and maximizing the derived function yields equation 1.11. This shows that firms who can adjust their price in the period t would need to account for current and future marginal costs. Hence, firms must account for factors that might affect the marginal cost such as the expected aggregate price index (see equation 1.9).

$$\left(\frac{p_t^*}{P_t} \right) = \left(\frac{\theta}{\theta - 1} \right) \frac{E_t \sum_{i=0}^{\infty} \omega^i \beta^i C_{t+i}^{1-\sigma} \varphi_{t+i} \left(\frac{P_{t+i}}{P_t} \right)^{\theta}}{E_t \sum_{i=0}^{\infty} \omega^i \beta^i C_{t+i}^{1-\sigma} \left(\frac{P_{t+i}}{P_t} \right)^{\theta-1}} \quad (1.11)$$

where

p_t^* - price chosen by all firms adjusting at time t .

If probability that firm would not adjust its prices would equal zero, all the firms would adjust their prices every period, which would yield same model as the real business cycles model. However, if probability of adjusting the price is between 0 and 1, price rigidities are present. This affects the aggregate price index P_t . Because only randomly chosen fraction of firms $(1 - \omega)$ adjust their prices each period, other fraction of firms ω inherits prices from the previous period. This is summarized by the equation 1.12.

$$P_t^{1-\theta} = (1 - \omega)(p_t^*)^{1-\theta} + \omega P_{t-1}^{1-\theta} \quad (1.12)$$

Final step to derive the basic NKPC is to combine equations (1.11) and (1.12). However, both equations require some alteration. Both parts of the average price level (1.12) should be divided by $p_t^{1-\theta}$. This yields equation 1.13.

$$1 = (1 - \omega)Q_t^{1-\theta} + \omega \left(\frac{p_{t-1}}{p_t}\right)^{1-\theta}, \quad Q_t^{1-\theta} = \left(\frac{p_t^*}{p_t}\right)^{1-\theta} \quad (1.13)$$

where

$Q_t^{1-\theta}$ – relative price chosen by price adjusting firms.

Equation 1.13 can further be rearranged into equation 1.14 to express the percentage deviation from the steady-state.

$$\hat{q}_t = \left(\frac{\omega}{1 - \omega}\right)\pi_t, \quad (1.14)$$

where

\hat{q}_t – relative price deviation from the steady state value,

π_t – inflation rate.

Next step is to approximate the optimal price choice (1.11), which is done in appendix 1. Approximation yields equation 1.15.

$$\hat{q}_t + \hat{p}_t = (1 - \omega\beta) \sum_{i=0}^{\infty} \omega^i \beta^i (E_t \hat{\varphi}_{t+i} + E_t \hat{p}_{t+i}), \quad \hat{q}_t + \hat{p}_t = p^* \quad (1.15)$$

where

\hat{p}_t – price deviation from the steady state value,

$\hat{\varphi}$ – marginal cost deviation from the steady state value.

Equation 1.15 states that the optimal nominal price p^* chosen by the price adjusting firms is the value of discounted expected future nominal marginal costs. This is in line with the equation (1.11). Equation 1.15 can be further rearranged into the equation 1.16 (see appendix 1).

$$\hat{q}_t = (1 - \omega\beta)\hat{\varphi}_t + \omega\beta(E_t\hat{q}_{t+1} + E_t\pi_{t+1}), \quad \pi_{t+1} = E_t\hat{p}_{t+1} - \hat{p}_t \quad (1.16)$$

Plugging equation 1.14 into the equation 1.16 to replace the \hat{q}_t produces the function shown in the equation 1.17.

$$\left(\frac{\omega}{1-\omega}\right)\pi_t = (1 - \omega\beta)\hat{\varphi}_t + \omega\beta\left(\left(\frac{\omega}{1-\omega}\right)E_t\pi_{t+1} + E_t\pi_{t+1}\right) \quad (1.17)$$

Multiplying both sides of the equation by $\left(\frac{1-\omega}{\omega}\right)$ and solving for π_t yields equation 1.18, which is the basic NKPC⁷.

$$\pi_t = \kappa\hat{\varphi}_t + \beta E_t\pi_{t+1}, \quad \kappa = \frac{(1-\omega)(1-\omega\beta)}{\omega} \quad (1.18)$$

The NKPC (1.18) shows that inflation rate at time t depends positively on the expected inflation rate and the marginal costs deviation from the steady state. Deviation of marginal costs affects the inflation rate because higher marginal costs would lead profit maximizing firms to increase their prices. However, magnitude of this effect on the inflation rate depends on two factors. One, it depends on the probability of firms not adjusting their prices ω . Higher probability of not leads to smaller effect on the inflation rate. This is explained by the equation 1.12. If probability of adjusting prices is low, only minority of firms adjust their prices and rest of the firms keep the same prices from the previous period. As the result, overall effect on the price level would be small. Second, the value of κ also depends on the subjective discount factor β . Lower value of the discount factor would lead to higher κ . This is explained by the fact that firms with higher preference for profit today would set their optimal prices higher (see equation 1.15).

Inflation expectations affect the inflation rate based on equation 1.11. When adjusting the price, firms must account for the future price levels. If firms expect high inflation, they will set the

⁷ Also called purely forward-looking NKPC.

prices higher at the time of adjustment. As a result, prices in the current period would increase leading to higher inflation. If firms value profit today higher than in the future, β would be low. Hence, effect of inflation expectation on the inflation rate would be smaller.

To conclude, the NKPC is derived from the households' demand for goods, which is used by the firms to maximize their profits and set the optimal price. However, since price rigidities are present firms cannot adjust their prices every period. Hence, firms must account for future profits, that depend on the marginal costs and aggregate price level.

1.3. The New Keynesian Phillips curve as part of the economy

Despite thesis focus being on the NKPC models, it is important to acknowledge that NKPC is a part of the 3-equation system. As per Clarida, *et al.* (1999) the basic New Keynesian framework would consist of the NKPC (see equation 1.18), dynamic New Keynesian IS curve, and some interest rate policy rule.

As per Walsh (2010), the dynamic New Keynesian IS curve can be derived from the same microfoundation as the NKPC (see section 3.2.). To be precise, the dynamic IS curve is the approximation of the Euler consumption condition (see equation 1.5). Assuming the marginal cost to be proxied by the output gap (see section 1.4. and Appendix 2), dynamic IS curve states that output gap in the current period is positively affected by the output gap expectations of households. At the same time, the output gap in the current period is negatively affected by the real interest rate. The logic behind the dynamic IS curve is that if households expect the output to increase in the future, they will begin consuming more in the current period (Clarida *et al.* 1999). If the real interest rate increases, households would prefer to consume less in the current period and lend money instead.

Finally, the interest rate policy rule can be represented by a Taylor rule (Galí 2018). The Taylor rule, proposed by Taylor (1993), states that nominal interest rate is positively affected by the inflation rate and the output gap. However, Taylor rule is not derived from the microfoundation of the New Keynesian theory. It is instead an empirical observation of central bank's behavior. Clarida *et al.* (1999) stated that microeconomic foundation can be provided to the monetary policy rule if central bank is assumed to maximize representative agents' utility. Nonetheless,

this approach might be misleading as different agent groups might experience shocks dissimilarly⁸. Another downside of the basic New Keynesian framework is the lack of the financial sector which, as was shown by the financial crisis of 2008, can have very noticeable impact on the economy (Galí 2018).

When the New Keynesian framework is considered as a whole, shocks to different equations can be introduced to analyze how the whole system reacts. To do so Dynamic Stochastic General Equilibrium (DSGE) models are used (Mavroeidis *et al.* 2014). However, due to their complexity⁹, DSGE models are beyond the scope of the thesis.

To conclude, previously derived NKPC (see section 1.2.), fulfills the role of the supply in the New Keynesian framework. Role of the demand is fulfilled by the households dynamic IS curve. Finally, the Taylor rule is commonly used to describe the central banks behavior. However, the Taylor rule is subject to the same criticism as the traditional Phillips curve (see section 1.1.), by being an empirical relationship rather than a theoretical one.

1.4. Overview of the New Keynesian Phillips curve empirical literature

Despite being part of the New Keynesian framework, the NKPC can be estimated and studied separately through the limited-information approach¹⁰. Early attempts to empirically estimate the NKPC revealed it to be challenging (Mavroeidis *et al.* 2014). One of the reasons might be the fact that marginal costs and inflation expectations are hard to measure empirically. Therefore, proxy variables are used. One of the most commonly used proxies for the marginal cost is the output gap, which is the difference between log of actual output and log of output under the flexible price level (see Appendix 2). The output gap is a theoretically suitable proxy, assuming there is a log-linear relationship between the marginal cost and the output gap. (Galí, Gertler 1999)

⁸ Example given by Clarida *et al.* (1999): factory workers and academic personnel would be affected by the economic downturn differently.

⁹ To estimate DSGE models empirically, Bayesian statistics are used.

¹⁰ Estimating the whole New Keynesian model (see section 1.3.) would be the full-information approach.

Based on the data for the United States from 1965 to 1993 Fuhrer and Moore (1995) concluded that the basic NKPC cannot account for the inflation persistence that is observed in the data¹¹. Fuhrer and Moore (1995) have also found that inflation rate during the studied period was positively correlated with the lagged output gap. This observation was later reinforced by Galí and Gertler (1999) who found that the output gap led the inflation rate, which is contrary to the NKPC theory.

To account for the inflation persistence, Galí and Gertler (1999) extended the basic NKPC (see equation 1.18) to include the lagged inflation rate. This addition became known as the hybrid NKPC. Furthermore, Galí and Gertler (1999) proposed the labor income share as an alternative to the output gap. Based on quarterly data from 1960 to 1997, both basic and hybrid NKPC estimates for the United States with labor income share as the marginal cost proxy were consistent¹² with the theory. Applying the same methodology to the euro area and using quarterly data from 1970 to 1998, Galí *et al.* (2001) found both basic and hybrid NKPC models to be consistent with the theory. Moreover, US and euro area estimates were found to be similar.

In contrast, Mazumder (2012) argued that labor income share implemented in those articles is an unsuitable proxy for the marginal cost. First, labor share is countercyclical which is opposite to the NKPC theory. Second, labor adjustment costs were ignored during its derivation. Based on quarterly data for the euro area from 1983 to 2008 Mazumder (2012) showed that when labor cost is procyclical and derived with adjustment costs in mind, basic and hybrid NKPC estimations yields wrongly signed coefficients. Countercyclical movement of the labor income share was also observed by Rudd and Whelan (2007) for the US data. In the sample period of 1960-2004 labor income share increased during recessions, while output gap decreased. As a result, both hybrid and basic NKPC estimates had no statistically significant relationship between inflation rate and labor income share.

As an alternative to the previously discussed marginal cost proxies, unemployment rate has emerged (see Zobl and Ertl 2020; Szafranek 2017). Applying short-term unemployment rate as the proxy for the marginal cost and using quarterly data spanning from 2003 to 2019, Zobl and

¹¹ NKPC used by Fuhrer and Moore (1995) was based on Taylor-Phelps, which is slightly different to Calvo pricing based NKPC used in the thesis.

¹² Statistically significant and correctly signed parameters of the NKPC.

Ertl (2020) have found that the basic NKPC¹³ is consistent with theory for Hungary, Romania, and Czech Republic. However, short-term unemployment was statistically insignificant for Poland, for which output gap provided a better fit. This is in line with the earlier article by Szafranek (2017). Based on the quarterly data for Poland from 2002 to 2015, Szafranek (2017) concluded that output gap or unemployment gap¹⁴ would be the best proxies for the marginal cost for Poland. Another important difference between those two articles compared to Galí and Gertler (1999) and Galí *et al.* (2001) was the assumption of the small open economy.

Theoretical extension of the NKPC into the small open economy (further referred to as SOE) was first proposed by Galí and Monacelli (2005), who assumed the world economy to be a continuum of the SOEs. Consequently, inflation in the SOE NKPC would depend on both domestic and external factors. Based on Galí and Monacelli (2005) SOE NKPC was estimated for the twelve new member states¹⁵ of the euro area by Mihailov *et al.* (2011a). Using output gap as a proxy for the marginal cost and terms of trade change as a proxy for the external factor, Mihailov *et al.* (2011a) found Czech Republic, Latvia, Bulgaria, and Cyprus estimates to be consistent with theory. This result is supported by Zobl and Ertl (2020) who found SOE NKPC to be valid for the Czech Republic. Mihailov *et al.* (2011a) also stated that estimates based on new member states provide more support for the SOE NKPC compared to the Western Europe or OECD countries. Reason might be higher output fluctuations and higher dependence of domestic inflation on foreign prices. In another article, Mihailov *et al.* (2011b) estimated SOE NKPC for 10 OECD countries¹⁶ with similar methodology to Mihailov *et al.* (2011a). While Germany, Netherlands, UK, and Switzerland had statistically significant and correctly signed external factor parameters, only UK had theoretically consistent SOE NKPC.

Another variable affecting estimation of the NKPC is the inflation expectations. One of the commonly used proxies is the leaded inflation¹⁷. However, it does not properly capture agents' expectations. Hence, it might be the reason for the empirical failings of the NKPC. Alternative to the leaded inflation is the usage of inflation expectations survey data. (Abbas *et al.* 2016).

¹³ Hybrid NKPC was found to have significant and correctly signed parameters, but overall lower explanation power. Hence, it was dismissed by the article authors.

¹⁴ Unemployment gap is the difference between actual and potential unemployment rates. Conceptually similar to the output gap.

¹⁵ Member states used: Poland, Hungary, Czech Republic, Slovakia, Slovenia, Estonia, Latvia, Lithuania, Bulgaria, Romania, Cyprus, Malta.

¹⁶ OECD countries used: Austria, Germany, Italy, France, Spain, Netherlands, UK, Canada, Sweden, Switzerland.

¹⁷ Actual value of inflation from the next period.

One of the first authors to use survey data as a proxy for the inflation expectations was Roberts (1995), who used the US annual data from 1949 to 1990. From the NKPC estimations, Roberts (1995) had concluded that both consumer and business survey forecasts provided results consistent with theory with both the unemployment rate and the output gap as the marginal cost proxies. At the same time, leaded inflation was appropriately signed but statistically insignificant with both of the marginal cost proxies. Roberts (1995) findings for the US were later confirmed by Adam and Padula (2011), who based on quarterly data from 1968 to 2003 found that usage of inflation forecast surveys yields theoretically consistent NKPC estimates with both the labor income share and the output gap. Implication of Adam and Padula (2011) findings is that usage of forecast survey data yields appropriately signed coefficient of the output gap for the US, contrary to Galí and Gertler (1999) findings with the leaded future inflation as expectations proxy.

Some authors tested applicability of the survey expectations to Europe. Based on aggregate data from twelve euro area members¹⁸, Paloviita (2006) found that in the sample period of 1977-2003 survey forecast data based hybrid NKPC estimates were consistent with theory. Hybrid NKPC estimated by Paloviita (2006) had correctly signed coefficients for labor income share and two different measures of the output gap. This result is also opposite to that achieved by Galí *et al.* (2001) who found output gap for the euro area to be incorrectly signed when leaded inflation expectations were used. Previously mentioned Zobl and Ertl (2020) had found estimates of the NKPC for a sample of countries in Central and Eastern Europe (CEE) to be consistent with theory when survey data was used as inflation expectations proxy.

Usage of survey-based inflation expectations might be a better reflection of agents' inflation expectations compared to the leaded inflation (Abbas *et al.* 2016). However, if survey-based inflation expectations are not rational this would compromise the microfoundation of the NKPC (Mavroeidis *et al.* 2014). Hence, the use of survey-based inflation expectations might provide a better fit to data at the cost of potentially compromising the microfoundation.

Further challenge to the NKPC estimation comes from the observed weakening of the relationship between the inflation rate and the marginal cost, which is known as the flattening of

¹⁸ Those members are: Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain.

the NKPC (Abbas *et al.* 2016). Potential flattening of the NKPC became the source of discussions following the financial crisis of 2008, when inflation rate's response to the recession and recovery was weaker than would have been expected. This discrepancy was observed in the US and to a lesser extent in the Euro area. (Bulligan and Vivano 2017) However, flattening of the NKPC was noticed even before the financial crisis. Kuttner and Robinson (2010) found that in the US, relationship between marginal cost and inflation rate has weakened over the sample period of 1960-2007. Kuttner and Robinson (2010) proposed that globalization has led to a decrease in the price adjustment frequency¹⁹. This is in line with Guerrieri *et al.* (2010) findings that NKPC extended to include the foreign competition had flatter slope of the NKPC than the basic model for the US data from 1983 to 2007. Blanchard (2016) have also found the slope of the NKPC for the US to flatten from early 1970s to early 2000s.

For Europe evidence on the flattening of the NKPC is mixed. Using wage inflation rate and unemployment rate as marginal cost proxies Bulligan and Vivano (2017) found that since the financial crisis of 2008 NKPC has become steeper in Italy, France, and Spain. Based on the microdata for Italy, they have proposed that price adjustment frequency has increased because of the structural changes in the euro area labor market. Bulligan and Vivano (2017) have also found that NKPC have become flatter for Germany following the financial crisis. For the Central and Eastern European sample of countries evidence on NKPC becoming flatter for Poland was found by Szafranek (2017). However, Zobl and Ertl (2020) found no evidence of the NKPC flattening for Poland, Czech Republic, Hungary, or Romania.

Flattening of the NKPC slope might have important implications for the monetary policy. If relationship between inflation rate and marginal costs is weak, it would require a significant decrease in the marginal cost to lower the inflation rate. Flattening of the NKPC might be especially important for the euro area. If countries have different slopes of the NKPC, effect of unified monetary policy on the inflation and output would be mismatched, which might lead to the desynchronization of member states' business cycles.

To conclude, depending on the choice of the NKPC type and combination of proxies, NKPC finds partial empirical support. However, some approaches used to empirically estimate the NKPC, such as usage of inflation survey forecast data and addition of inflation persistence, are

¹⁹ In other words, increase in the price non-adjustment probability parameter ω (see equation 1.18).

derived from empirical observations. Hence, while these additions may provide a better description of inflation dynamics and theoretically consistent coefficients, they may not be in line with the microfoundation of the NKPC.

1.5. Overview of empirical studies for the Baltic States

Based on the quarterly data²⁰ from 1995 to 2005 Dabušinskas and Kulikov (2007) have estimated both closed and open economy hybrid NKPC models with labor income share and output gap as proxies for the marginal costs²¹. Leaded inflation was used as a proxy for the inflation expectations. For all of the Baltic states forward-looking inflation expectations generally had higher weights. Marginal costs proxies were correctly signed in all of the models. However, only labor income share was statistically significant and only for one type of models. Moreover, coefficients of marginal costs were small, which implied a weak impact of marginal costs on the inflation rate.

In a later study of the new euro area member states, Mihailov *et al.* (2011a) have estimated closed and open economy NKPC models. Data for the Baltic states covered the period from 1995 to 2007 (Mihailov *et al.* 2010)²². Open-economy model used by Mihailov *et al.* (2011a) featured the change in terms of trade as external factor proxy. This approach is different to that of Dabušinskas and Kulikov (2007) who modeled open economy through the addition of the imported intermediate goods into the production function. Mihailov *et al.* (2011a) used output gap and leaded inflation as proxies. In the open economy models external factor is appropriately signed and statistically significant for all of the Baltic states. Moreover, inflation expectations are theoretically consistent for all of the Baltic states. However, marginal costs are statistically significant and appropriately signed only for Latvia. Basic closed economy NKPC estimates were theoretically consistent for all of the Baltic states. Hybrid closed economy NKPC estimates were theoretically consistent only for Estonia. Latvia and Lithuania had statistically insignificant marginal costs. Backward-looking inflation expectations in the hybrid models were found to be generally statistically insignificant, which is partially in line with Dabušinskas and Kulikov (2007).

²⁰ Data from 1995 to 2005 was used for Estonia. For Latvia and Lithuania sample period was 1995-2005.

²¹ The study by Dabušinskas and Kulikov (2007) is unpublished and only available as a working paper.

²² Mihailov *et al.* (2010) is a working paper, which has additional information concerning data and estimation results from Mihailov *et al.* (2011a) article.

Using data on the new euro area member states from 1999 to 2007 Vašíček (2010) have found different results to that of Mihailov *et al.* (2011a). Similarly to Mihailov *et al.* (2011a) output gap and leaded inflation were used as proxies. However, Vašíček's (2010) hybrid open economy model included two external factors, which were real effective exchange rate (REER) and euro area inflation rate²³. For all of the Baltic states both forward- and backward-looking inflation expectations were theoretically consistent. However, contrary to Mihailov *et al.* (2011a) and Dabušinskas and Kulikov (2007) backward-looking inflation expectations had higher weights. Marginal costs were significant and correctly signed only for Lithuania, which is contrary to Dabušinskas and Kulikov (2007) who found marginal costs to be correctly signed for all of the Baltic states in the hybrid open economy models. Finally, external factor represented by the REER was insignificant for all of the Baltic states. However, foreign inflation rate was found to be theoretically consistent for some of the Baltic states.

To conclude, NKPC empirical estimation finds partial support for the Baltic states. Mihailov *et al.* (2011a) have found theoretically consistent basic closed economy NKPC models for all of the Baltic states. Evidence on the validity of the hybrid NKPC is mixed. While Vašíček (2010) shows backward-looking inflation expectations to be statistically significant and correctly signed for all the Baltic, Mihailov *et al.* (2011a) finds backward-looking expectations to be theoretically consistent only for Estonia. Evidence on the open economy NKPC for the Baltic states is also mixed. Mihailov *et al.* (2011a) find change in terms of trade to be theoretically consistent for all the Baltic states. Vašíček (2010) estimates were consistent only for the foreign inflation rate variable and only for Estonia and Latvia, with other external factors being inconsistent with theory.

Articles described in this section are dated and do not include the data after the financial crisis of 2008. Hence, issue of the NKPC flattening for Baltic states is not considered in the literature. Revisiting the NKPC estimation for the Baltic states using recent data might give new insights into the NKPC validity for the CEE region.

²³ Euro area interest rate represents the foreign interest rate.

2. DATA AND ESTIMATION METHODS

2.1. Requirements for the estimation of the New Keynesian Phillips curves

To provide a foundation for the empirical analysis, three hypotheses are proposed based on the empirical literature (see sections 1.4. and 1.5.):

1. For the Baltic states marginal costs have lower impact on the inflation rate after the financial crisis of 2008;
2. For the Baltic states, forward-looking inflation expectations have higher impact on the inflation rate compared to the backwards-looking inflation expectations;
3. For the Baltic states external factors are in line with the small open economy NKPC theory.

Taken together, these hypotheses cover main issues concerning the empirical estimation of the NKPC both in the Baltic states (section 1.5.) and in general (section 1.4.). First hypothesis is related to the NKPC flattening (see section 1.4.), as this issue was not considered for the Baltic states. No extensions of the NKPC beyond the hybrid (see equation 2.2) and open-economy (see equations 2.3 and 2.4) models are required.

Hypothesis two is based on the Baltic states related empirical literature, which highlighted that inflation expectations in the Baltic states are predominantly forward-looking in the hybrid models (see section 1.5.). Following Galí, Gertler (1999) hybrid NKPC can be derived through the addition of the backwards-looking price-setting behavior into the average price equation (1.12). This is shown in the equation 2.1.

$$P_t = (1 - \omega)[(1 - \varpi)P_t^f + \varpi P_t^b] + \omega P_{t-1}, \quad P_t^b = \bar{P}_{t-1}^* + \pi_{t-1} \quad (2.1)$$

where

ϖ – fraction of backward-looking firms,

P_t^f – price set by forward-looking firms,

P_t^b – price set by backwards-looking firms,

\bar{P}_{t-1}^* – average price set by price adjusting firms in the last period.

Equation 2.1 states that fraction of firms $(1 - \varpi)$ are forward-looking firms who follow the basic NKPC model (see equation 1.15). Fraction of firms ϖ are backwards-looking firms, who set prices by taking the average price set during the last price setting round \bar{P}_{t-1}^* and adjusting it with inflation rate from the last period. Combining (2.1) with (1.15) yields the hybrid NKPC. Reduced-form hybrid NKPC is given in the equation 2.2.

$$\pi_t = \kappa \hat{\phi}_t + \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1}, \quad \gamma_f + \gamma_b = 1 \quad (2.2)$$

where

γ_f – weight of forward-looking expectations,

γ_b – weight of backwards-looking expectations.

Equation 2.2 shows that inflation in the current period positively depends on the marginal costs, forward-looking inflation expectations and backwards-looking inflation expectations, which is the lagged inflation rate. Deep parameters of the reduced-form hybrid NKPC (2.2) are given in system (2.3).

$$\begin{cases} \kappa \equiv (1 - \varpi)(1 - \omega)(1 - \omega\beta)\phi^{-1} \\ \gamma_f \equiv \omega\beta\phi^{-1} \\ \gamma_b \equiv \varpi\phi^{-1} \\ \phi \equiv \omega + \varpi[1 - \omega(1 - \beta)] \end{cases} \quad (2.3)$$

Logic behind equation 2.3. is similar to that of the basic NKPC (1.18). However, higher fraction of backwards-looking firms ϖ leads to higher weight of the backwards-looking expectations γ_b and lower value of κ , because these firms set prices equal to the average price chosen by the price adjusting firms in the previous period. Higher value of β leads to lower weight of forward-looking expectations γ_f and higher weight of backwards-looking expectations γ_b . If fraction of backwards-looking firms ϖ is 0, hybrid NKPC (2.2) becomes the basic NKPC (1.18).

Third hypothesis is based on the open economy extension of the NKPC. For some of the Baltic states, external factors²⁴ were found to be statistically significant and correctly signed (see Mihailov *et al.* 2011a; Vašíček 2010). Furthermore, Zobl and Ertl (2020) have found estimation results for the open economy NKPC models to be theoretically consistent for some of the CEE region countries. The basic NKPC must be extended to accommodate the assumption of the open

²⁴ External factors are sources of inflation that come from abroad.

economy. However, open economy addition requires substantial changes to the microfoundation and NKPC derivation process, which is beyond the scope of the thesis. Hence, only reduced-form models will be estimated. Reduced-form of the basic open economy NKPC based on Zobl and Ertl (2020) is given in the equation 2.4.

$$\pi_t = \kappa \hat{\varphi}_t + \beta E_t \pi_{t+1} + \alpha \pi_t^i \quad (2.4)$$

where

π_t^i – External source of inflation.

Equation 2.4 states that inflation in the current period depends positively on the inflation expectations, changes in the marginal costs and external factor. Hybrid open economy model can also be estimated (see equation 2.5).

$$\pi_t = \kappa \hat{\varphi}_t + \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \alpha \pi_t^i \quad (2.5)$$

Estimation results of described models might be affected by the addition of the constant. Some authors have included it in the empirical estimations (see Zobl and Ertl 2020; Szafranek 2017; Abbas *et al.* 2016). Others have not (see Mihailov *et al.* 2011a; Paloviita 2006; Galí and Gertler 1999). However, exclusion of constant, either statistically significant or insignificant, might yield biased estimation results. This is because residuals might not have zero mean if constant is excluded. Furthermore, slope of the regression would be forced to go through the origin, which might not fit the data. Therefore, models with the constant included are estimated as the baseline. As an alternative, models with the constant excluded are also estimated and briefly discussed.

2.2. Choice of data

For the empirical estimations quarterly data for the Baltic states from 2002Q2 to 2019Q4 is used. Choice of time period is motivated by the data availability. Year 2020 is excluded from the data sample, due to the beginning of the coronavirus pandemic, which may have affected chosen variables. Choice of region is motivated by the NKPC estimation results for the Baltic states (see section 1.3.).

Variables required to empirically estimate the NKPC are the inflation rate and proxies for the marginal costs, inflation expectations, and the external factor. As was discussed earlier choice of

proxies impacts the estimation results. Hence, a variety of proxies should be used. Usage of different proxy combinations and NKPC model specifications is in line with the empirical literature (see Zobl and Ertl 2020; Szafranek 2017; Mihailov *et al.* 2011a). Data used in the thesis is described in the Table 1.

Table 1. Sources and descriptions of the variables used in the thesis

Variable	Source	Seasonal adjustment	Data transformation
Inflation rate	Eurostat All-items HICP (2015=100), monthly data	EViews multiplicative census X-12	Monthly indices converted to quarterly by averaging, percentage change from quarter to quarter is calculated
Output gap	Eurostat GDP, chain linked volume, 2015=100, quarterly data	seasonally and calendar adjusted by the Eurostat	HP filter is used to derive the output gap as deviation of log GDP from its long-run trend
Labor share gap	Eurostat Compensation of employees as % of GDP (ESA 2010), quarterly data	Seasonally and calendar adjusted by the Eurostat	HP filter is used to derive the labor share gap as deviation of the log labor share from its long-run trend
Unemployment gap	Eurostat unemployment rate, % of total active population, quarterly data	Seasonally and calendar adjusted by the Eurostat	HP filter is used to derive the unemployment gap as deviation of the log unemployment from its long-run trend
Leaded inflation rate	Quarterly inflation rate	Not required	Actual inflation rate in the next period
Consumer inflation expectations	European Commission Business and consumer survey, inflation perceptions, monthly data	EViews multiplicative census X-12	Data is converted from monthly to quarterly by averaging and transformed following Dias et al. (2010) methodology
REER index change	REER index, quarterly (2010=100)	EViews multiplicative census X-12	Percentage change of the index from quarter to quarter is calculated
Commodity inflation rate	International Monetary Fund All Commodity Price Index, monthly (2016=100)	EViews multiplicative census X-12	Index is converted into local currencies, percentage change of the index from quarter to quarter is calculated

Sources: Eurostat (2021a, 2021b, 2021c, 2021d, 2021e), European Commission (2021), International Monetary Fund (2021); author's calculations

Note: exchange rates used for the adjustment of the commodity price index are Eesti Pank (2021, 2010), Latvijas Banka (2019a, 2019b), Lietuvos Bankas (2018a, 2018b).

Variables, other than the inflation rate, shown in the Table 1 can be divided into three groups. First group comprises the three marginal cost proxies. Output gap corresponds to the traditional microfoundation. Labor share corresponds to the approach used by Galí and Gertler (1999) and Galí *et al.* (2001). Usage of the labor share gap is explained by the nonstationarity of the labor share. Unemployment gap corresponds to a modern approach which focuses on the labor market performance (see Zobl, Ertl 2020; Szafranek 2017). It is important to note that unemployment

gap should be negatively related to the inflation rate. Hence, in all the models (see section 2.1.), marginal cost should be negatively signed when unemployment gap is used as a proxy.

To calculate the gap variables, traditional 2-sided²⁵ Hodrick-Prescott filter (HP filter) with smoothing parameter value of 1600 is used. However, according to Hamilton (2018) traditional HP filter introduces spurious dynamics into the filtered data. As a result, values at the end of the HP filtered sample differ from those in the middle. As an alternative, Hamilton (2018) proposed a detrending method based on the regression of values lagged by 2 years (Hamilton filter). Nevertheless, Hodrick (2020) suggested that in case of data sample being small compared to the magnitude of changes in the economy, Hamilton filter might yield misleading results. Hodrick's (2020) suggestion might be relevant to the data used in the thesis. Hence, despite the Hamilton (2018) critique, HP filter is used in the thesis.

Next group of proxies is the inflation expectations. Leaded inflation is the actual value of inflation one period ahead, which is commonly used in the NKPC literature (see Mihailov *et al.* 2011a; Dabušinskas and Kulikov 2007; Galí and Gertler 1999). Alternative proxy is the survey-based inflation expectations (further referred as the survey expectations), which was used by Zobl and Ertl (2020). One openly accessible source of the survey-based information for the euro area is the business and consumer survey conducted by the European Commission (further referred to as the EC survey). It is important to note that, EC survey of inflation expectations focuses on the consumers. However, as was noted by Coibion and Gorodnichenko (2015), this should not compromise the NKPC theory, as consumers might simultaneously be small firm owners.

EC survey on consumer inflation expectations is conducted by asking respondents' opinion on how much inflation is going to increase in the next twelve months compared to the previous twelve months. Five single choice answers are provided: inflation is going to increase faster, increase at the same rate, increase slower, stay the same, or decrease. Additional answer is "don't know". For each answer, a fraction of responses is reported.

²⁵ One side is the forwards-looking component, second side is the backwards-looking component.

Following Dias *et al.* (2010) qualitative survey results can be transformed into quantitative inflation expectations²⁶. To do so probability thresholds for answer categories are calculated based on the inverse of the normal standard distribution. From thresholds, adjustment score is calculated, which is multiplied by the ‘moderate’ inflation rate to get the inflation expectations. ‘Moderate’ inflation rate is assumed to be the inflation rate that is perceived as the baseline by respondents at the time of answering. Empirically, ‘moderate’ inflation rate is assumed to be a long-term trend of the HP filtered inflation rate series. However, usage of HP filter might be subject to the Hamilton (2018) critique. Furthermore, as was pointed out by Coibion and Gorodnichenko (2015), consumers might perceive changes in prices based on the goods they consume. As a result, inflation expectations can be formed by agents based on their subjective experiences rather than on the ‘moderate’ inflation.

Finally, change in the real effective exchange rate (REER) and change in the commodity price index are used as proxies for the external factor. Both of these variables were found to be statistically significant for the open-economy NKPC by Zobl and Ertl (2020). Commodity price index was also found to be statistically significant and correctly signed by Szafranek (2017). REER may impact domestic inflation through changes in the exchange rates of the trading partners. Change in commodity index reflects effect of changes in prices of different world commodities, such as oil, on the domestic inflation.

2.3. Descriptive statistics

To summarize the data, descriptive statistics are provided for the variables discussed in the previous section (see Table 1). In the Figure 2, inflation rate is plotted against the survey expectations. Figure is divided into three parts, where each part represents one of the Baltic states.

As seen from the Figure 2, before the financial crisis inflation exhibits a growth trend for all the Baltic states. After the crisis, from year 2010 onwards, all the Baltic states show similar movement with different level of variation.

²⁶ The same method was used by Zobl and Ertl (2020) to derive the inflation expectations for their article.

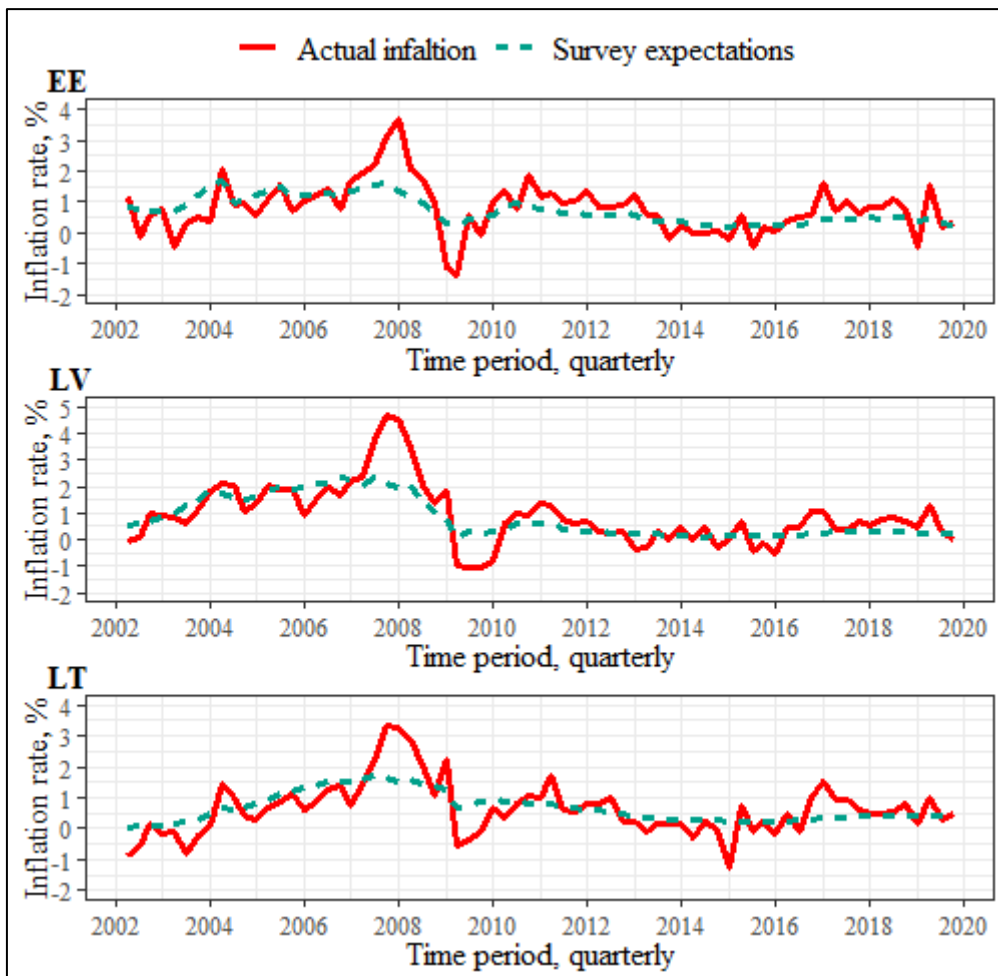


Figure 2. Inflation rate and survey expectations for the Baltic states, 2002Q2-2019Q4
 Source: Eurostat (2021a), European Commission (2021) ;author's calculations
 Notes: EE, LV, and LT refer to Estonia, Latvia, and Lithuania, respectively.

For all the Baltic states, survey expectations mirror the general movement in the inflation rate. This is expected since survey expectations are based on the long-term trend of the inflation rate. Leaded inflation is not included in the graph since it is the actual value of inflation in the next period²⁷. Nevertheless, Figure 2 implies that leaded inflation would have significantly higher variance compared to the survey expectations. In the Figure 3, the traditional marginal cost proxies are shown.

²⁷ Visually, that would be exactly the same graph as shown in the Figure 2 but leading by one quarter.

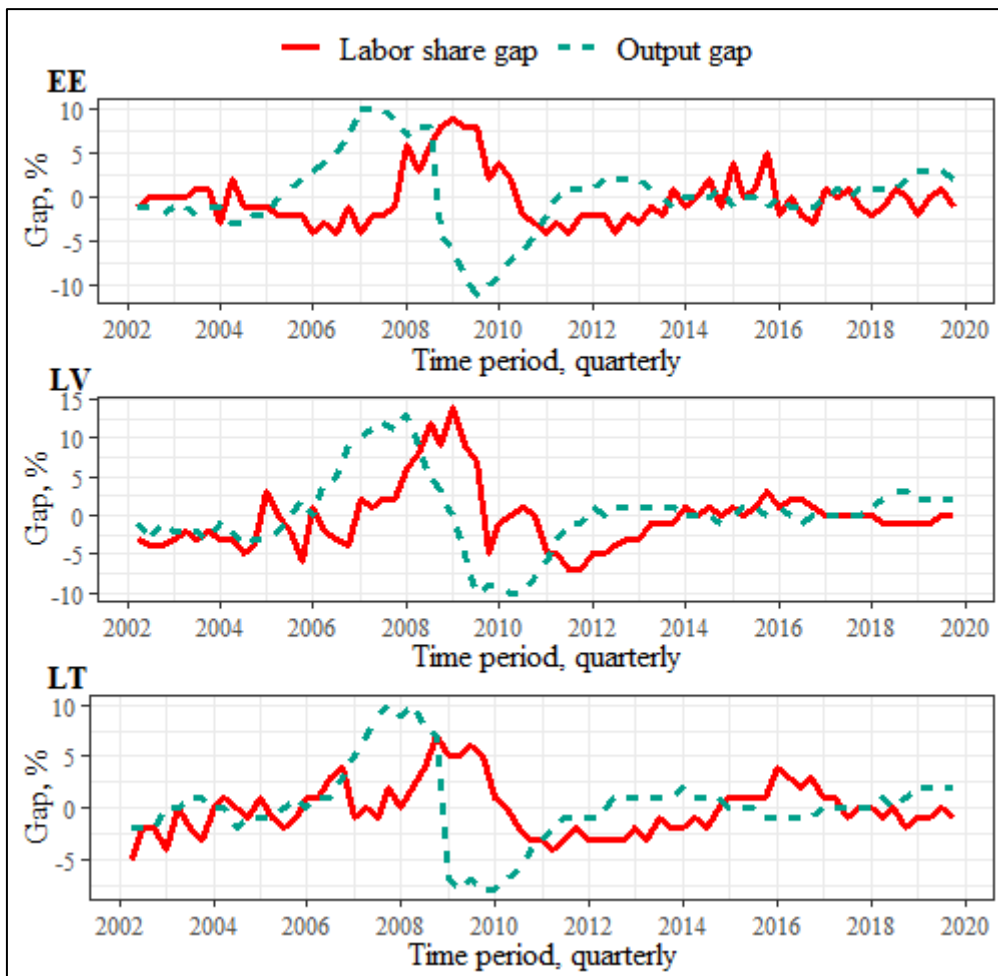


Figure 3. Labor share gap and output gap for the Baltic states, 2002Q2-2019Q4
 Source: Eurostat (2021b, 2021c); author's calculations
 Notes: see Figure 2.

Figure 3 shows that for all the Baltic states, output gap was rapidly increasing from 2005 to 2008. This might indicate that the pre-crisis output was unnaturally high because of the financial 'bubble', bursting of which led to the financial crisis afterwards. Output gap seems to show a procyclical movement. After the crisis output gap movement indicates similar business cycles for all the Baltic states.

Labor share gap significantly increased during the crisis for all the Baltic states. This suggests that it is countercyclical, which is in line with the labor share critique (see Mazumder 2012; Rudd and Whelan 2007). Furthermore, countercyclical movement is supported by the labor share gap movement being opposite to that of the output gap. In the postcrisis period, movement of the labor share gap for all the Baltic states is similar. In the Figure 4 unemployment gap is plotted for the Baltic states.

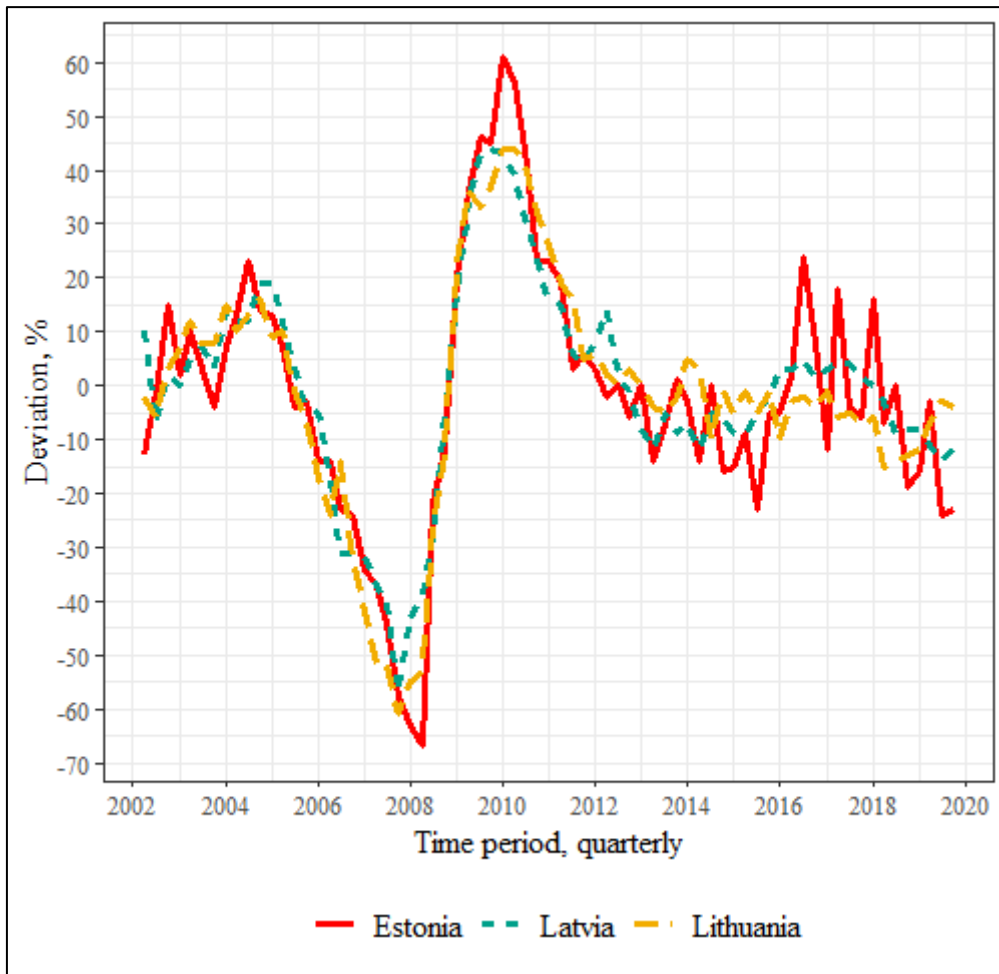


Figure 4. Unemployment gap for the Baltic states, 2002Q2-2019Q4
 Source: Eurostat (2021d); author's calculations

From the Figure 3 it can be seen that unemployment is also procyclical. All the Baltic states show similar movement before and during the crisis. Similar movement can also be seen after the crisis. However, Estonia shows significantly higher variance between 2013 and 2019.

Finally, two external factors: changes in the commodity prices and changes in the REER are given in Figures 5 and 6, respectively.

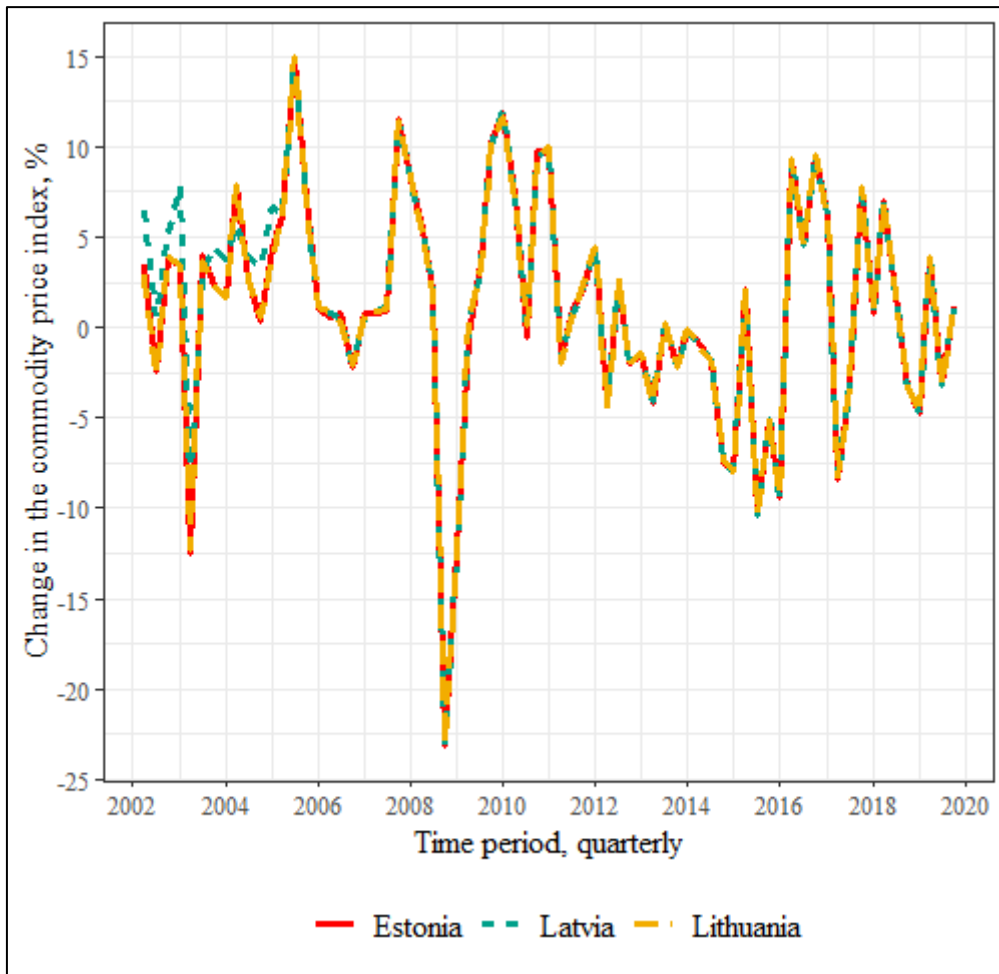


Figure 5. Change in the commodity price index in the Baltic states, 2002Q2-2019Q4
 Source: International Monetary Fund (2021); author's calculations

Figure 5 shows that change in commodity price index is essentially the same for all the Baltic states since 2005. This is because by that time, all the Baltic states had their currencies pegged to the euro²⁸. Change in the commodity price index depends on both prices of the commodities and euro to dollar exchange rate. Similarly to inflation, change in the commodity price index seems to be procyclical. While a downward trend can be observed from 2010 to 2016, there seems to be no general trend in the commodity price index movement.

²⁸ Both Estonia and Lithuania pegged its currencies to the euro in early 2002. Latvia did the same in early 2005.

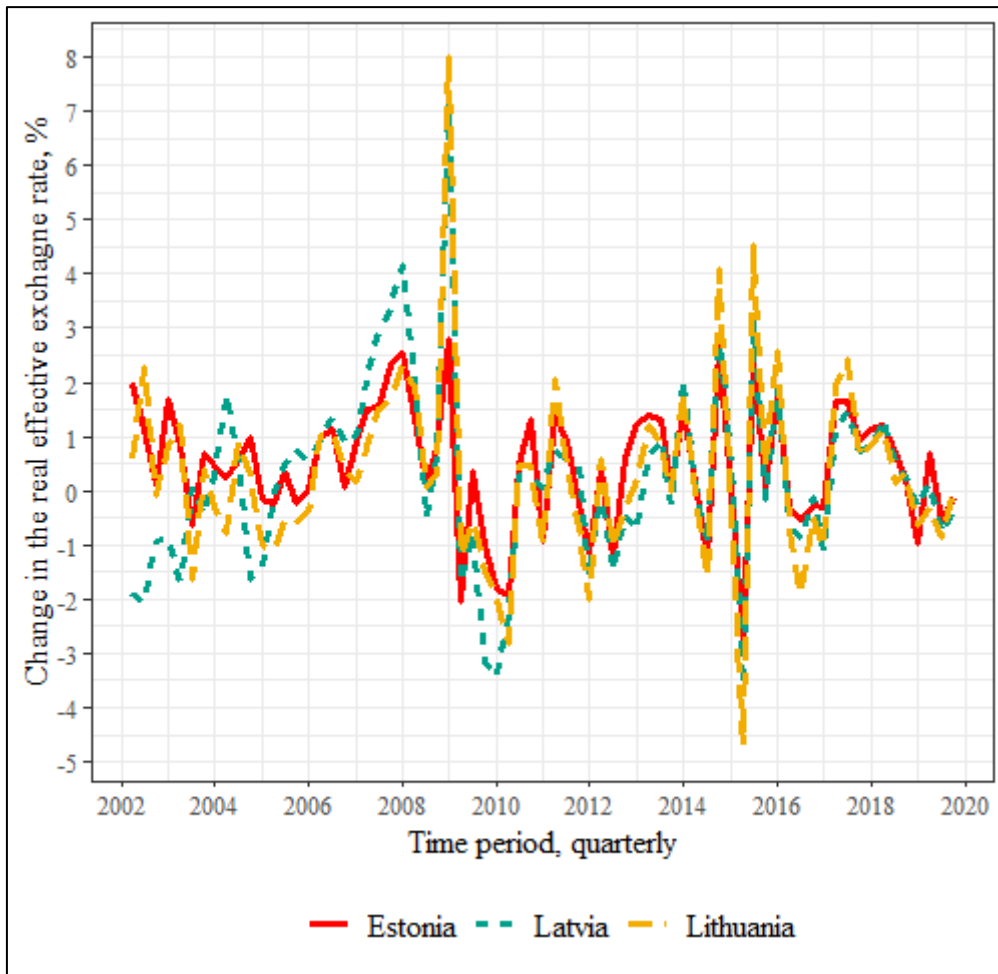


Figure 6. Change in the real effective exchange rate for the Baltic states, 2002Q2-2019Q4
 Source: Eurostat (2021e); author's calculations

Figure 6 shows that before the crisis, from 2002 to 2006, fluctuations in the REER were different for every state. During the crisis, movement in the REER became similar for all the Baltic states although with different variance. In the periods following the crisis, movement became more synchronized. This is especially noticeable from 2013 onwards. Differences in the level of variation might be explained by different inflation rates (see Figure 2).

To conclude the overview, summary statistics are provided in the Table 2. Because changes in the commodity prices are approximately the same for all of the Baltic states (see Figure 4) this variable is excluded from the Table 2 and is instead given in the extended table in the Appendix 3.

Table 2. Summary statistics for the Baltic states

		Inflation rate, %	Labor gap, %	Output gap, %	Unemployment gap, %	Survey expectations, %	Change in REER, %
EE	Mean	0.806	-0.094	0.241	-1.521	0.722	0.456
	Median	0.793	-0.783	0.080	-2.573	0.600	0.472
	Maximum	3.649	8.628	9.652	60.666	1.671	2.796
	Minimum	-1.385	-4.491	-11.033	-66.712	0.214	-2.755
	Std. Dev.	0.833	3.010	4.275	24.044	0.415	1.148
	Skewness	0.458	1.237	-0.105	-0.062	0.680	-0.357
	Kurtosis	4.770	4.186	3.940	4.059	2.223	3.080
LV	Mean	0.911	-0.293	0.263	-0.813	0.794	0.217
	Median	0.705	-0.414	0.239	0.115	0.329	0.230
	Maximum	4.712	13.909	12.637	43.546	2.343	7.249
	Minimum	-1.083	-7.164	-9.958	-57.112	0.059	-3.586
	Std. Dev.	1.142	4.057	4.784	19.876	0.751	1.733
	Skewness	1.097	1.245	0.312	-0.174	0.859	0.858
	Kurtosis	4.937	5.227	4.030	3.723	2.109	5.950
LT	Mean	0.634	-0.161	0.232	-1.659	0.662	0.291
	Median	0.547	-0.416	0.262	-1.636	0.459	0.230
	Maximum	3.348	6.851	10.071	44.483	1.730	7.995
	Minimum	-1.242	-4.741	-8.492	-61.468	0.063	-4.724
	Std. Dev.	0.867	2.569	3.804	22.143	0.466	1.737
	Skewness	0.907	0.789	0.321	-0.481	0.834	1.149
	Kurtosis	4.568	3.227	4.317	3.957	2.469	8.020

Source: Eurostat (2021a, 2021b, 2021c, 2021d, 2021e), European Commission (2021); author's calculations

Notes:

1. Std. Dev. is the standard deviation.
2. REER is the real effective exchange rate.

All of the gap variables have positive kurtosis values, which implies the presence of outliers in the tails of the distribution. Furthermore, distributions of the gap variables are skewed. Summary statistics for other variables also indicate the presence of outliers. To conclude, both visual analysis of data and summary statistics point to the presence of extreme observations around the time of the financial crisis of 2008.

To account for the presence of the financial crisis related extreme observation, data is split into 2 samples. Sample one is named 'crisis' and covers periods from 2002Q2 to 2010Q4. This sample includes observations from the precrisis period and from the crisis itself. Sample two is named 'postcrisis' and spans from 2010Q4 to 2019Q4. This sample reflects a stabilized postcrisis

period. Separation of data into two samples also allows to analyze in a simple manner²⁹ if flattening of the NKPC has occurred (see section 1.4.).

2.4. Data stationarity testing

To avoid spurious regressions, stationarity tests are conducted. Augmented Dickey-Fuller (ADF) unit root test is used to test the presence of the unit root. The null hypothesis of the ADF test states that unit root is present in the data, alternative hypothesis states that data is stationary. However, DeJong *et al.* (1992) found Dickey-Fuller (DF) unit root test to have low statistical power³⁰ if sample size is under 50 observations. Same authors have suggested that DF and consequently ADF tests should not be performed on data samples smaller than 100 observations because of the low statistical power.

Kwiatkowski *et al.* (1992) noted that rejection of the null hypothesis requires strong evidence. Hence, ADF test would indicate the presence of the unit root in most economic time series. To address this, Kwiatkowski *et al.* (1992) proposed the KPSS³¹ stationarity test, which has a null hypothesis of trend stationarity and alternative hypothesis of the unit root. Moreover, Kwiatkowski *et al.* (1992) have shown that KPSS test have sufficient power even for the samples as small as 30 observations if number of lags is not excessive. Hence, usage of both ADF and KPSS test should provide robust results.

Results of the aforementioned tests for the full sample are given in the Table 3. Test results strongly support the stationarity of the inflation rate for Estonia and Lithuania. For Latvia, test results are mixed. While KPSS test strongly supports the stationarity, ADF test indicates the presence of the unit root. This might be explained by the sample size, which is 74. Therefore, as was suggested by DeJong *et al.* (1992), ADF test might have low statistical power and falsely reject the null hypothesis. Stationarity of the survey expectations is generally supported by the KPSS test. ADF test results support stationarity only for Estonia. Stationarity of change in the REER and change in the commodity index is strongly supported by both tests for all the Baltic states.

²⁹ For more advanced NKPC curve time stability testing methods, see Zobl and Ertl (2020).

³⁰ Statistical power is the probability of correctly rejecting the null hypothesis. Low power implies a high probability of type II error *i.e.* falsely accepting the null hypothesis.

³¹ Named after the authors of the article: Kwiatkowski-Phillips-Schmidt-Shin (KPSS).

Table 3. Stationarity test results for selected variables, full sample

	Test	Inflation	Survey expectations	REER	Commodity index
EE	ADF (Intercept)	-4.311***	-1.775	-7.821***	-5.860***
	ADF (Trend and intercept)	-4.395***	-3.712**	-7.802***	-5.913***
	ADF (None)	-1.985**	-3.748***	-7.012***	-5.797***
	KPSS (Intercept)	0.215***	0.790	0.105***	0.189***
	KPSS (Trend and intercept)	0.081***	0.104***	0.052***	0.051***
LV	ADF (Intercept)	-2.510	-1.139	-6.428***	-5.713***
	ADF (Trend and intercept)	-3.008	-2.407	-6.372***	-5.862***
	ADF (None)	-1.916*	-1.075	-6.366***	-5.599***
	KPSS (Intercept)	0.380**	0.696*	0.086***	0.319***
	KPSS (Trend and intercept)	0.092***	0.113***	0.087***	0.053***
LT	ADF (Intercept)	-3.899***	-1.514	-8.558***	-5.845***
	ADF (Trend and intercept)	-3.925**	-2.368	-8.498***	-5.899***
	ADF (None)	-2.070**	-0.625	-8.387***	-5.782***
	KPSS (Intercept)	0.151***	0.361**	0.049***	0.186***
	KPSS (Trend and intercept)	0.132**	0.113***	0.044***	0.052***

Source: Eurostat (2021a, 2021e), European Commission (2021), International Monetary Fund (2021); author's calculations

Notes:

1. For the ADF tests *, **, *** refer to the rejection of the null hypothesis at 10%, 5%, 1% significance level, respectively.
2. For the KPSS tests *, **, *** refer to the acceptance of the null hypothesis at 10%, 5%, 1% significance level, respectively.

Stationarity test results for the gap variables are excluded from the Table 2, because usage of the HP filter should yield stationary data by default. To confirm the stationarity, tests are applied to gap variables in the Appendix 4. Test results generally support the stationarity of the gap variables.

As was discussed in the end of the previous section, data is also split into two subsamples. Hence, stationarity tests are also applied to the subsamples. Stationarity tests applied to the 'crisis' sample (see Appendix 5) support stationarity of the external factors. Stationarity of the inflation in the 'crisis' sample is weakly supported by the ADF tests. However, KPSS tests support the stationary. Same pattern can be observed for the gap variables and survey expectations. Difference between KPSS and ADF results might be explained by the small sample size, as 'crisis' sample includes only 35 observations.

Stationarity tests applied to the 'postcrisis' sample (see Appendix 6) strongly support stationarity of external factors, survey expectations, and gap variables. Inflation is only weakly stationary, as

ADF tests generally indicate the presence of the unit root. This, once again, might be related to the small sample size, which is only 36 observations.

In conclusion, ADF and KPSS tests generally indicate the stationarity of chosen variables. However, stationarity tests for the ‘crisis’ sample might be affected by the presence of outliers. In all samples, KPSS tests suggest stronger stationarity compared to the ADF tests, which might be explained by the low power of the ADF test in small samples.

2.5. Empirical estimation methods

Generalized method of moments (GMM) is commonly used to empirically estimate the NKPC (see Zobl and Ertl 2020; Mihailov *et al.* 2011a; Galí and Gertler 1999). A brief overview of the GMM estimation method is given in the following paragraphs based on the Hamilton (1994).

GMM owes its name to the moments, which are descriptive parameters of the distribution³². A consistent population parameter can be estimated based on the choice of moments and a sample of observations. This is known as the classical method of moments estimator. However, several moments can be used to estimate one population parameter. As a result, there might be no exact solution, because a single parameter cannot match several sample moments simultaneously. Instead, minimization of a criterion function is used to estimate a parameter value that matches all the required moment conditions as closely as possible. Minimized criterion function comprises moment conditions weighted by the weighting matrix. This is the basis of the generalized method of moments (GMM). For GMM estimation, orthogonality conditions are used. However, GMM itself is a framework, which means that classical method of moments is its special case³³.

GMM estimator depends on the weights chosen for the weighting matrix. Initially, criterion function is estimated with some arbitrary weight matrix and then re-estimated based on the achieved GMM estimates. One approach is to iterate this process until convergence. Another method is to use the continuously updated estimator, which computes the weighting matrix and estimator simultaneously until convergence (CUE) (see Zobl and Ertl 2020). The choice of the

³² First to fourth moments are mean, variance, skewness, and kurtosis, respectively.

³³ OLS is also a special case of the GMM.

weighting matrix can also depend on the presence of serial correlation in the data. Hence, Newey-West estimation method can be used for the heteroscedasticity and autocorrelation (HAC) robust standard errors³⁴.

To estimate the NKPC instrumental variables are implemented to account for potential endogeneity of the explanatory variables (see Abbas et al. 2016). Hence, instrumental variable GMM (IVGMM) is used. As an example, orthogonality condition for the basic reduced-form NKPC estimated by the IVGMM is given in the equation 2.6.

$$E[z_t(\pi_t - \kappa\hat{\varphi}_t - \beta E_t\pi_{t+1})] = 0 \quad (2.6)$$

where

z_t – is a vector of instrumental variables.

Generally, orthogonality conditions for the IVGMM are stated by moving all of the equation variables to the left-hand side³⁵. Equation 2.6 states that explanatory variables, which in given case are marginal costs $\hat{\varphi}_t$ and inflation expectations $E_t\pi_{t+1}$, are correlated with the instrumental variables z_t and uncorrelated with the error term. Number of instruments equals the number of moments.

Estimation results can be diagnosed using a variety of tests. First, Hansen J-test is used to determine whether the model is correctly specified (see Zobl and Ertl 2020; Szafranek 2017; Abbas *et al.* 2016). The null hypothesis of Hansen J-test states that model is specified correctly, alternative hypothesis states that model is misspecified.

Estimation results can also be affected by the weak instruments, which are instruments that are weakly correlated with the explanatory variables. In EViews, which is used for the empirical estimations, weak instruments can be tested following Stock and Yogo (2001). Stock and Yogo (2001) test for weak instruments is based on the Cragg-Donald F-statistic and a set of Stock-Yogo critical values. Idea of the test is to see how much instrumental variable (IV) estimator bias exceeds that of the ordinary least squares (OLS). Null hypothesis states that instruments are weak, alternative hypothesis states that instruments are valid. Null hypothesis is accepted if Cragg-Donald statistic does not exceed the Stock-Yogo critical values. However,

³⁴ Newey-West method affects the variance-covariance matrix, which is used for the weighting matrix.

³⁵ Orthogonality conditions for all the described NKPC variations (see section 2.1.) can be derived in this way.

Stock-Yogo estimation method is valid only for the Two-Stage Least Squares (2SLS), which is a special case of the GMM. To get the 2SLS weighting matrix is multiplied by the estimated variance of residuals. Some alternative methods to test for the weak instruments exist, such as The Kleibergen-Paap rk Wald statistic tests used by Zobl and Ertl (2020).

To estimate the NKPC models, internal instrument variables are used. Mihailov *et al.* (2010) have used 6 lags of inflation rate, 5 lags of marginal cost proxy, and a constant. Similar instruments were also used by Szafranek (2017), who have included a constant, 4 lags of inflation, 2 lags of marginal cost proxy and additional instruments for external factors and inflation expectations. Based on previous empirical literature and initial estimation results, following set of instruments was chosen for the thesis: 5 lags of inflation, 3 lags of marginal cost proxy, and a constant. In models with survey expectations, following Zobl and Ertl (2020), one lag of survey expectations is added to previously described set of instruments. In hybrid models, first lag of inflation is removed from the instruments set, as it becomes part of the estimated model.

To conclude, GMM results depend on the choice of the weighting matrix and updating method. Hence, different combinations would affect the estimation results. Hence, 2SLS is used as the baseline estimation method. While 2SLS has less options, it provides results reproducibility. Furthermore, as was mentioned earlier, Stock and Yogo (2001) test for the weak instruments is valid only for the 2SLS. Therefore, usage of 2SLS as a baseline estimation method allows to assess the validity of chosen instruments. Based on the results, suitable GMM specification can be chosen as a robustness check. For example, if baseline estimation results indicate the presence of autocorrelation and weak instruments, usage of CUE estimator and Newey-West HAC weighting matrix might be warranted.

3. EMPIRICAL ESTIMATION AND ANALYSIS

3.1. Basic closed economy New Keynesian Phillips curves

To begin, basic closed-economy NKPC models are estimated using three different marginal cost proxies. For each marginal cost proxy, both leaded inflation and survey expectations are used. To account for the structural break and analyze potential flattening of the NKPC, estimations are done on the full sample and also on two subsamples (see section 2.3.). Models with the constant are estimated as the baseline. Models without the constant are estimated as an alternative and are discussed in the text.

Throughout the following sections, to assess the correspondence of estimated models to the NKPC theory, argument of theoretical consistency will be used. This means that all the variables, except for the constant, should be correctly signed and statistically significant (in line with the models described in section 2.1.). Proxies for inflation expectations should have a positive relationship with the inflation rate in all the models. This relationship must also be positive for the output gap and the labor share gap, while it should be negative for the unemployment gap. If these criteria are not met, models are not in line with the NKPC theory. Some additional criteria, such as coefficient values, are discussed in the text.

3.1.1. Models with output gap as marginal costs proxy

First, models with the leaded inflation and the output gap are estimated. Estimation results for the full sample are theoretically consistent only for Estonia (see Table 4.). Computation of the deep parameters reveals the Calvo probability for Estonia to be 88%, which suggests that prices are updated every 8.02 quarters. While Hansen J-statistic suggests that the model is specified correctly, low values of Cragg-Donald F-statistic suggest that instruments might be weak. Durbin-Watson statistic shows some positive autocorrelation.

The estimation results for the subsamples are theoretically consistent only for the ‘crisis’ sample for Latvia (see Appendix 7). Calvo probability for Latvia is estimated to be 86%, which suggests that prices are updated every 7.18 quarters.

Table 4. Basic NKPC with output gap and leaded inflation, full sample

	Estonia	Latvia	Lithuania
Constant	0.281 (0.174)	-0.138 (0.171)	-0.063 (0.189)
Output gap	0.062** (0.026)	-0.001 (0.029)	0.025 (0.038)
Leaded inflation	0.649*** (0.193)	1.153*** (0.163)	1.045*** (0.239)
Observations	72	72	72
R-squared	0.380	0.596	0.253
Durbin-Watson	2.589	1.886	2.611
Hansen J-statistic	10.906**	7.336***	3.142***
Weak instrument (Cragg-Donald F)	3.401	3.931	3.455

Source: Eurostat (2021a, 2021b); author’s calculations

Notes:

1. Standard errors are given in parentheses under the coefficient estimates.
2. For the variables *, **, *** denotes statistical significance at 10%, 5%, 1% respectively.
3. For weak instrument test critical values are 18.30, 10.43, and 6.22 for 5%, 10%, and 20% bias thresholds, respectively.

For the ‘postcrisis’ sample for Latvia and Estonia it can be observed that the coefficient of the output gap becomes smaller in value and statistically insignificant, which might indicate a flattening of the NKPC (see Appendix 7). If the constant is excluded, output gap becomes statistically insignificant for all countries and time samples. Hence, basic NKPC models with no constant are theoretically inconsistent.

When survey expectations are used, the estimation results seem to provide stronger support for the basic NKPC for the Baltic states, compared to models with the leaded inflation. Estimation results for models with the output gap and survey expectations are theoretically consistent for the full sample for all the Baltic states (see Table 5).

Calvo probability is estimated to be 78% for Estonia, 77% for Latvia, and 73% for Lithuania. This suggests that prices would be adjusted every 4.50, 4.27, and 3.76 quarters, respectively. For Estonia price adjustment happens more frequently compared to models with the leaded inflation.

Table 5. Basic NKPC with output gap and survey expectations, full sample

	Estonia	Latvia	Lithuania
Constant	0.124 (0.161)	0.124 (0.120)	-0.034 (0.143)
Output gap	0.074*** (0.020)	0.076*** (0.019)	0.095*** (0.022)
Survey expectations	0.955*** (0.202)	0.981*** (0.118)	1.003*** (0.179)
Observations	72	72	72
R-squared	0.501	0.714	0.533
Durbin-Watson	1.406	0.863	1.467
Hansen J-statistic	13.120**	23.015	9.578***
Weak instrument (Cragg-Donald F)	32.002	76.219	27.160

Source: Eurostat (2021a, 2021b), European Commission (2021); author's calculations

Notes: see Table 4.

For models shown in the Table 5 weak instrument statistic value suggests that 2SLS bias is low and does not exceed 5%. Thereofer, instruments are sufficiently strong. Hansen J-test supports the specifications of models for Estonia and Lithuania. For Latvia, a different set of instruments might be needed. However, all models exhibit positive autocorrelation according to the Durbin-Watson statistic.

Estimation results for the subsamples are generally theoretically inconsistent, except for the 'crisis' sample for Lithuania (see Table 6). Calvo probability for Lithuania is estimated to be 70%, which is close to the Calvo probability estimated for the full sample.

Table 6. Basic NKPC with output gap and survey expectations, subsamples

	Estonia		Latvia		Lithuania	
	Crisis	Postcrisis	Crisis	Postcrisis	Crisis	Postcrisis
Constant	0.172 (0.770)	-0.421** (0.196)	0.768 (0.573)	-0.312 (0.191)	-0.208 (0.456)	-0.158 (0.249)
Output gap	0.075* (0.041)	-0.009 (0.050)	0.125*** (0.038)	0.031 (0.041)	0.098*** (0.033)	-0.047 (0.077)
Survey expectations	0.878 (0.705)	2.437*** (0.421)	0.513 (0.389)	2.838*** (0.684)	1.092** (0.418)	1.546*** (0.557)
Observations	32	37	32	37	32	37
R-squared	0.492	0.575	0.709	0.450	0.592	0.339
Durbin-Watson statistic	1.182	2.299	0.811	1.699	1.487	1.806
Hansen J-statistic	8.319***	6.116***	12.041***	3.297***	6.485	8.038**
Weak instrument (Cragg-Donald F)	3.534	10.847	10.276	17.239	8.912	19.254

Source: Eurostat (2021a, 2021b), European Commission (2021); author's calculations

Notes: see Table 4.

Same pattern as in models with the leaded inflation (see Appendix 7) is observed. For all the Baltic states, the coefficient value of the output gap becomes smaller in absolute value and statistically insignificant in the ‘postcrisis’ sample. Hence, potential flattening of the NKPC is observed for all the Baltic states.

If constant is excluded, estimation results for the full sample are similar to those shown in the Table 5. Furthermore, Calvo probability for the full sample is approximately the same for all the Baltic states and is equal to 74% or 3.87 quarters on average. Estimation results for the subsamples, however, differ slightly from those shown in the Table 6. When the constant is excluded, the estimation results for the ‘crisis’ sample become theoretically consistent for Estonia and Latvia (see Appendix 8). This is because survey expectations become statistically significant. However, as was discussed earlier (see section 2.1.), exclusion of the constant might lead to biased estimation results. Furthermore, exclusion of constant affects only the ‘crisis’ samples, which includes extreme observations from the financial crisis. Nevertheless, the same pattern of output gap being statistically insignificant and smaller in value in the ‘postcrisis’ sample is observed for all the Baltic states. Hence, exclusion of constant does not contradict previous results.

To conclude, models with leaded inflation find support for the full sample for Estonia and for the ‘crisis’ sample for Latvia when leaded inflation is used as the proxy for the inflation expectations. When survey expectations are used instead, the basic NKPC finds stronger support, as estimation results become theoretically consistent for the full sample for all the Baltic states. Irrespective of the inflation expectations proxy choice, evidence of the NKPC flattening is observed.

3.1.2. Models with labor share gap as marginal costs proxy

Continuing the analysis, models with the labor share gap and leaded inflation are estimated. Results provide some support for the basic NKPC models for Latvia. However, the estimates are theoretically consistent only for the full sample and the ‘crisis’ subsample (see Table 7). The Calvo probability for the full sample is estimated to be 75%. For the ‘crisis’ sample, same parameter is estimated to be 72%, which is smaller compared to the value from models with the output gap (see section 3.1.1.). Hansen J-statistic suggests that models are specified correctly. Durbin-Watson statistic suggests no autocorrelation. However, weak instruments might be present, as Cragg-Donald F-statistic is generally low.

Table 7. Basic NKPC with leaded inflation and labor share gap, Latvia

	Crisis	Postcrisis	Full
Constant	-0.246 (0.283)	-0.055 (0.167)	-0.112 (0.134)
Labor share gap	0.093** (0.037)	-0.041 (0.036)	0.048* (0.026)
Leaded inflation	1.072*** (0.142)	1.069*** (0.351)	1.130*** (0.107)
Observations	32	37	72
R-squared	0.684	-0.057	0.631
Durbin-Watson	1.998	2.848	1.994
Hansen J-statistic	7.922***	1.005***	5.048***
Weak instrument (Cragg-Donald F)	3.732	1.236	7.524

Source: Eurostat (2021a, 2021c); author's calculations

Notes: see Table 4.

The estimation results for Estonia and Lithuania are not theoretically consistent neither for the full sample nor for the subsamples (see Appendix 9). However, for the 'postcrisis' samples for Latvia (see Table 7) and Lithuania (see Appendix 9) the coefficients of the labor share gap are shown to have lower absolute values than those for the 'crisis' samples. However, the opposite is observed for Estonia (see Appendix 9). If the constant is excluded, conclusions remain the same.

If survey expectations are used, results are mixed. For Latvia and Lithuania, there are cases where both survey expectations and labor share gap are statistically significant and correctly signed (see Table 8). However, coefficients of survey expectations significantly exceed the value of 1. This affects the Calvo probability, which is revealed to be 54% for the 'crisis' sample for Latvia and 29% for the 'postcrisis' sample for Lithuania. Estimation results for Estonia are generally theoretically inconsistent. Even when both labor share gap and survey expectations are statistically significant, as seen for the full sample (see Appendix 10), labor share gap is incorrectly signed.

Similarly to the results for the models with the leaded inflation rate, the coefficient of the labor share gap for Estonia increases in value in the 'postcrisis' sample (see Appendix 10). The same is observed for Lithuania (see Table 8), while the results for Latvia still support the flattening of the NKPC. If the constant is excluded from the models, conclusions generally remain the same. Only affected model is the 'crisis' sample for Lithuania, which becomes theoretically inconsistent.

Table 8. Basic NKPC with survey expectations and labor share gap, Latvia and Lithuania

	Latvia			Lithuania		
	Crisis	Postcrisis	Full	Crisis	Postcrisis	Full
Constant	-0.979** (0.375)	-0.267 (0.158)	-0.016 (0.127)	-1.027*** (0.365)	-0.685** (0.267)	-0.232 (0.149)
Labor share gap	0.084** (0.035)	0.028 (0.033)	0.035 (0.026)	-0.056 (0.059)	0.175** (0.071)	-0.032 (0.039)
Survey expectations	1.682*** (0.227)	2.799*** (0.639)	1.198*** (0.115)	1.952*** (0.333)	3.174*** (0.724)	1.331*** (0.183)
Observations	32	37	72	32	37	72
R-squared	0.690	0.442	0.648	0.579	0.276	0.491
Durbin-Watson	0.861	1.667	0.737	0.976	2.107	1.112
Hansen J-statistic	13.924	4.069	27.932	8.617	4.304	14.280
Weak instrument (Cragg-Donald F)	5.924	18.849	13.985	5.289	5.198	11.606

Source: Eurostat (2021a, 2021c), European Commission (2021); author's calculations

Notes: see Table 4.

To conclude, similar to the results with the output gap (see section 3.1.1.), basic NKPC models with leaded inflation rate are supported for the 'crisis' sample for Latvia. However, the Calvo probability is lower in models with the labor share gap. The estimation results for the models with the survey expectations are theoretically inconsistent. Estimation results for Latvia suggest that NKPC is flatter in the 'postcrisis' sample. However, NKPC seems to become steeper for Estonia. For Lithuania there is evidence of both flattening and steepening of the NKPC, depending on the proxy of the inflation expectations.

3.1.3. Models with unemployment gap as marginal costs proxy

Finally, unemployment gap is used as the proxy for the marginal cost. First, the combination of the unemployment gap and leaded inflation is estimated. Estimation results generally do not support the basic NKPC for the Baltic states (see Appendix 11), except for the 'crisis' sample for Estonia (see Table 10). The coefficient of the unemployment gap is correctly signed since the theoretical model predicts it to be negatively related to the inflation rate.

To calculate the Calvo probability for models with the unemployment gap as the marginal cost proxy, the microfoundation (see section 1.2.) would have to be changed, which is beyond the scope of the thesis. Therefore, only reduced-form models are estimated and discussed in this section.

Table 10. Basic NKPC with led inflation and unemployment gap, Estonia

	Crisis	Postcrisis	Full
Constant	0.447 (0.283)	0.554*** (0.192)	0.061 (0.185)
Unemployment gap	-0.011** (0.005)	0.028** (0.012)	-0.007 (0.005)
Leaded inflation	0.583** (0.216)	0.251 (0.268)	0.927*** (0.199)
Observations	32	37	72
R-squared	0.513	0.183	0.247
Durbin-Watson	2.253	2.298	2.761
Hansen J-statistic	7.623***	7.306***	5.763***
Weak instrument (Cragg-Donald F)	2.746	2.604	3.197

Source: Eurostat (2021a, 2021d); author's calculations

Notes: see Table 4

As shown in the Table 10, the NKPC becomes steeper in the 'postcrisis' sample for Estonia. However, it also becomes incorrectly signed. For Latvia, the coefficient of the unemployment gap becomes statistically insignificant and smaller in value for the 'postcrisis' sample (see Appendix 11), which is in line with the results from the previous sections. Similar pattern is observed for Lithuania. However, for Lithuania unemployment gap is statistically insignificant in both subsamples.

If the constant is excluded, unemployment gap becomes statistically insignificant for all the models. As a result, estimates for the 'crisis' sample for Estonia (see Table 10) become theoretically inconsistent if constant is excluded.

Using survey expectations as a proxy for the marginal cost yields theoretically consistent basic NKPC models for the full sample for all the Baltic states (see Table 11). While weak instrument statistic indicates that chosen instruments are valid, Hansen J-statistic suggests that model for Latvia is misspecified. For Estonia and Lithuania same statistic supports the model specification. However, Durbin-Watson statistic indicates that positive autocorrelation is present for all the models.

The estimation results for the subsamples are generally theoretically inconsistent, except for the 'crisis' sample for Lithuania (see Appendix 12). However, for both Latvia and Lithuania unemployment gap is statistically significant in the 'crisis' sample and insignificant in the 'postcrisis' sample. Furthermore, for both countries the coefficient value of the unemployment

gap is smaller in the ‘postcrisis’ sample. This is in line with the results from models with the output gap (see section 3.1.1.) and partially in line with the results from models with the labor share gap (see section 3.1.2.). However, for Estonia, slope of the NKPC seems to become steeper, which is in line with the results for models with the labor share gap (see section 1.3.2.) and contradictory to results for models with the output gap (see section 3.1.1.).

Table 11. Basic NKPC with survey expectations and unemployment gap, full sample

	Estonia	Latvia	Lithuania
Constant	0.014 (0.158)	0.128 (0.120)	-0.039 (0.145)
Unemployment gap	-0.009** (0.004)	-0.018*** (0.004)	-0.012*** (0.004)
Survey expectations	1.121*** (0.195)	0.990*** (0.116)	1.020*** (0.182)
Observations	72	72	72
R-squared	0.475	0.713	0.536
Durbin-Watson	1.285	0.849	1.311
Hansen J-statistic	16.524*	22.650	4.365***
Weak instrument (Cragg-Donald F)	19.558	54.393	56.825

Source: Eurostat (2021a, 2021d), European Commission (2021); author’s calculations

Notes: see Table 4.

If the constant is excluded only the estimation results for the ‘crisis’ samples for Estonia and Latvia are affected. These models become theoretically consistent (see Appendix 13). Furthermore, same conclusions about the change in the slope of the NKPC hold for all the states. However, as was discussed earlier, presence of extreme observations in the ‘crisis’ sample and exclusion of constant might yield misleading results.

To conclude, the basic NKPC models with unemployment gap and led inflation is supported only for the ‘crisis’ sample for Estonia. This is partially in line with the results for models with the output gap. Models with survey expectations, however, find support for the full sample for all the Baltic states, similarly to models with the output gap (see section 1.3.1.). Moreover, similar to models with the labor share gap (see section 1.3.2.), evidence on the flattening of the NKPC is observed only for Latvia and Lithuania. For Estonia evidence of steepening of the NKPC is found instead.

3.2. Hybrid closed economy New Keynesian Phillips curves

Estimated basic models can be extended into the hybrid specification by including the lagged inflation rate. Similarly to the previously estimated models, different combinations of marginal cost and inflation expectations proxies are used. Models with the constant are considered as the baseline. Models with the constant excluded are briefly discussed in text.

First, hybrid models with the output gap and leaded inflation are estimated. Estimation results are revealed to be theoretically inconsistent, as output gap is generally statistically insignificant. However, in some cases both lagged and leaded inflation rates are statistically significant. As a result, weights of forward- and backwards-looking inflation expectations can be compared. For Estonia, weight of the forward-looking inflation expectations is higher. For Latvia, weight of the backwards-looking inflation expectations is higher. Results do not depend on the presence of the constant. When survey expectations are used, results are mixed. In models with constant included, estimation results are theoretically inconsistent in all cases, except for the full sample for Latvia (see Appendix 14). For this sample all the variables, except the constant, are statistically significant and correctly signed. Furthermore, contrary to the models with the leaded inflation, weight of the forward-looking inflation expectations is higher. If constant is excluded, conclusions generally remain the same.

Following the same order as in the basic models, hybrid models with the labor share gap are estimated next. Estimation results for models with leaded inflation are theoretically inconsistent, as labor share gap is statistically insignificant for all states and samples. However, for Estonia both lagged and leaded inflation rates are statistically significant for the full sample. For this sample forward-looking inflation expectations have higher weight. If constant is excluded, estimation results are similar.

Using the survey expectations instead of the leaded inflation rate yields no theoretically consistent hybrid NKPC models. For the full sample for Estonia all the variables are statistically significant, but labor share gap is incorrectly signed (see Table 9). Furthermore, for Estonia and Lithuania weight of the forward-looking expectations is higher. For Latvia, weight of the backwards-looking inflation expectations is slightly higher, which is also partially in line with previous results.

Table 9. Hybrid NKPC with survey expectations and labor share gap, full sample

	Estonia	Latvia	Lithuania
Constant	-0.023 (0.158)	-0.075 (0.103)	-0.159 (0.149)
Labor share gap	-0.057* (0.033)	-0.024 (0.026)	-0.029 (0.036)
Survey expectations	0.714** (0.281)	0.562*** (0.204)	0.793** (0.342)
Lagged inflation	0.412** (0.171)	0.592*** (0.162)	0.440* (0.224)
Observations	72	72	72
R-squared	0.493	0.772	0.570
Durbin-Watson	2.361	1.825	2.173
Hansen J-statistic	10.722**	5.112***	4.616***
Weak instrument (Cragg-Donald F)	3.412	3.008	2.100

Source: Eurostat (2021a, 2021c), European Commission (2021); author's calculations

Notes: see Table 4.

Finally, applying the combination of the unemployment gap and leaded inflation rate yields no theoretically consistent hybrid NKPC models. Both lagged and leaded inflation rates are statistically significant only for the full sample for Latvia, for which weight of the forward-looking inflation expectations is higher. Exclusion of constant does not yield any theoretically consistent models. However, both types of inflation expectations become statistically significant for the full sample for Estonia and Latvia (see Appendix 15). In both cases forward-looking inflation expectations have higher weights, which is in line with previous results.

If survey expectations are combined with the unemployment gap, results are theoretically consistent only for the full sample for Latvia (see Table 10). Nevertheless, survey expectations and lagged inflation are statistically significant for the full sample for Estonia and Latvia. For both countries forward-looking inflation expectations have higher weight. Hence, results for Estonia are in line with previously estimated models.

If constant is excluded conclusions remain mostly the same. For Latvia however, estimation results for the 'crisis' sample become statistically significant and theoretically consistent (see Appendix 16). Nonetheless, presence of extreme observations in the 'crisis' sample might be the reason.

Table 10. Basic NKPC with survey expectations and unemployment gap, Latvia

	Estonia	Latvia	Lithuania
Constant	-0.059 (0.157)	0.041 (0.107)	-0.066 (0.146)
Unemployment gap	-0.001 (0.005)	-0.012** (0.005)	-0.012*** (0.004)
Survey expectations	0.669** (0.305)	0.692*** (0.173)	1.028*** (0.304)
Lagged inflation	0.499** (0.226)	0.350** (0.150)	0.032 (0.223)
Observations	72.000	72.000	72.000
R-squared	0.476	0.708	0.534
Durbin-Watson	2.440	1.494	1.372
Hansen J-statistic	8.616***	4.403***	4.135***
Weak instrument (Cragg-Donald F)	2.126	4.238	2.342

Source: Eurostat (2021a, 2021d), European Commission (2021); author's calculations

Notes: see Table 4.

To conclude, hybrid extension of the NKPC finds very limited support for the Baltic states. Hybrid NKPC is theoretically consistent only for the full sample for Latvia and only when combination of the unemployment gap and survey expectations is used (see Table 10). However, for Estonia, forward-looking inflation expectations consistently have higher weight. For Latvia results are inconsistent and depend on the combination of proxies. Nevertheless, forward-looking inflation expectations seem to be dominant For Lithuania, both types of the inflation expectation are statistically significant only in one case (see Table 9), in which forward-looking expectations have higher weight.

3.3. Open economy New Keynesian Phillips curves

Closed-economy models (see sections 3.1. and 3.2.) can be further analyzed by assuming the economy to be open. To do so external factor is added into the model. Two different external factors, which are relative changes in the REER and relative changes in the commodity prices, are considered. External factors are assumed to be exogenous. Hence, no changes in the instruments (see section 2.5.) are required. To account for the omitted variable bias, all of the models from the previous sections are re-estimated. To reduce the number of models required, only 'crisis' and 'postcrisis' samples are used.

3.2.1. Models with changes in the real effective exchange rate as the external factor

Estimation results for the models with the output gap are theoretically inconsistent. For the basic models change in the REER is statistically significant and correctly signed only for the crisis sample for Latvia. Hybrid models are also theoretically inconsistent. Results do not depend on the presence of constant or choice of the inflation expectations proxy.

Estimation results for the basic labor models with the labor share gap are not in line with the NKPC theory. However, for the ‘crisis’ samples for Latvia and Lithuania change in the REER is statistically significant and correctly signed. Hybrid models are theoretically inconsistent. Results do not depend on the presence of constant or choice of the inflation expectations proxy.

Similar to the previously described results, estimation results for the models with the unemployment gap are generally theoretically inconsistent. For basic NKPC models with the leaded inflation rate change in the REER is statistically significant only for the ‘crisis’ samples for Latvia and Lithuania. Hybrid NKPC models are also unanimously theoretically inconsistent. Results do not depend on the presence of constant.

To conclude, when change in the REER is used as the external factor proxy, open economy NKPC estimates are unanimously theoretically inconsistent. However, for Estonia change in the REER is consistently statistically insignificant. For Latvia, same variable is statistically significant for the ‘crisis’ samples irrespective of the marginal cost proxy choice. For Lithuania, change in REER is statistically significant in models with the labor share gap or the unemployment gap.

3.2.2. Models with changes in the commodity price index as the external factor

Following same order of estimation as in the previous subsection, models with the output gap and leaded inflation are estimated first. Estimation results are generally not theoretically consistent. In the basic models with leaded inflation, change in the all commodity price index (further referred to as change in commodity prices) is statistically significant only for the ‘postcrisis’ sample for Estonia. In hybrid models, external factor is unanimously statistically insignificant. Results for both model specifications do not depend on the presence of the constant. Models with the survey expectations yield same results for the hybrid models. For basic models with the survey expectations estimation results are theoretically inconsistent.

However, external factor is statistically significant for the ‘crisis’ sample for Latvia. If constant is excluded (see Appendix 16) estimation results for the ‘crisis’ sample for Latvia become theoretically consistent, as both leaded inflation rate and output gap become statistically significant. However, these results might be biased due to the constant exclusion and presence of outliers in the sample.

Results for models with the labor share gap are generally theoretically inconsistent. When, leaded inflation is used change in the commodity prices is statistically significant for the ‘postcrisis’ sample for Estonia. Hybrid models with leaded inflation are unanimously theoretically inconsistent. When survey expectations are used, estimation results for the ‘crisis’ sample for Latvia are partially theoretically consistent (see Table 12). However, value of the survey expectations coefficient exceeds the value of 1, which contradicts the NKPC theory.

Table 12. Basic open-economy NKPC, survey expectations, labor share gap, constant

	Estonia		Latvia		Lithuania	
	Crisis	Post crisis	Crisis	Post crisis	Crisis	Post crisis
Constant	-1.799** (0.748)	-0.753 (0.824)	-1.850** (0.660)	-0.295 (0.245)	-0.974* (0.481)	-0.414 (0.352)
Labor share gap	0.110 (0.068)	0.145 (0.243)	0.205** (0.075)	0.031 (0.039)	-0.068 (0.089)	0.118 (0.084)
Survey expectations	2.573*** (0.640)	3.457 (2.334)	1.842*** (0.324)	2.919 (1.025)	1.938*** (0.354)	2.398** (0.983)
External factor	0.026 (0.029)	0.024 (0.028)	0.157** (0.074)	-0.005 (0.031)	-0.009 (0.049)	0.029 (0.027)
Observations	30	37	30	37	30	37
R-squared	0.540	0.631	0.427	0.395	0.566	0.385
Durbin-Watson statistic	0.840	2.236	1.713	1.700	1.005	1.887
Hansen J-statistic	12.428**	5.672***	2.683***	3.622***	8.007***	3.740***
Weak instrument (Cragg-Donald F)	1.521	0.070	0.579	0.705	0.530	1.161

Source: Eurostat (2021a, 2021c), European Commission (2021), International Monetary Fund (2021); author’s calculations

Notes:

1. External factor is the change in the world commodity price index.
2. For additional information see Table 4.

Finally, when unemployment gap is used as the marginal cost proxy, models remain theoretically inconsistent. However, in models with the leaded inflation, change in the commodity prices is statistically significant and correctly signed for the ‘postcrisis’ sample for Latvia. In models with the survey expectations, external factor is correctly signed and statistically significant for the ‘crisis’ sample for Latvia. If constant is excluded conclusions generally remain the same.

However, in models with the survey expectations, change in the commodity prices become correctly signed and statistically significant.

To conclude, usage of the change in the commodity prices as a proxy for the external factor yields partially theoretically consistent results only for the ‘crisis’ sample for Latvia (see Table 12). However, similar to the previous section, some patterns in the statistical significance of the external factor can be observed. For the ‘postcrisis’ sample for Estonia, change in the commodity prices is statistically significant in the basic models with the output gap and labor share gap, irrespective of the inflation expectations type. For Latvia, the same variable is statistically significant for the ‘crisis’ sample for all the marginal cost proxies. For Lithuania, change in the commodity prices is statistically significant for the ‘postcrisis’ sample, but only when the combination of unemployment gap and leaded inflation rate is used.

3.4. Robustness analysis

As was shown in the previous sections, some of the theoretically consistent estimation results are subject to weak instruments and autocorrelation. Both of those issues can potentially be addressed through the CUE GMM estimator paired with the Newey-West HAC weighting matrix (further referred as the CUE GMM). However, when CUE GMM is used instead of the 2SLS, the results differ from those described in previous sections. For models estimated using the CUE GMM, the statistical significance of variables generally improves. However, the coefficients of inflation expectations generally significantly exceed the value of 1 or are negatively signed. Hence, they contradict the NKPC theory. These conclusions generally hold for all the marginal cost and inflation expectations proxies. Furthermore, most of the models which have statistically significant variables when CUE GMM is used, also have high negative values of R-squared. This means that the fit to data of those models is very poor³⁶.

These results might be explained by the instruments choice. Zobl and Ertl (2020) have used CUE GMM in their article and have highlighted that number of instruments should be minimal. Number of instruments used in the thesis, however, was higher than that used by Zobl and Ertl

³⁶ Essentially, a straight line would fit the data better, as it would have the R-squared value of approximately 0.

(2020). As a result, combination of relatively small sample size and big instrument sets may have led to poor empirical and theoretical performance of the CUE GMM models.

Contradicting results of the CUE GMM models should not discredit the 2SLS estimations. Due to previously described poor empirical performance of the CUE GMM, it might be incomparable to the 2SLS estimates. Hence, problem of weak instruments and autocorrelation remains unaddressed in the thesis. In the future research, however, problem of weak instruments might be further studied by applying different instrument sets within one estimation method.

3.5. Discussion of results

Results for the closed economy models (see section 3.1.) are partially in line with the previous literature. Out of three used marginal cost proxies, the labor share gap has the worst performance, irrespective of the inflation expectations proxy. The coefficient of the labor share gap is statistically insignificant or incorrectly signed in those models. Incorrect coefficient sign might be explained by the counter-cyclicality of the labor share gap (see section 2.3.), which is in line with Mazumder (2012).

Models with the output gap and unemployment gap are theoretically consistent for the full sample for all the Baltic states when survey expectations are used, whereas models with leaded inflation are supported only for Estonia. Better performance of survey expectations in models is partially in line with Zobla and Ertl (2020), Adam and Padula (2011) and Roberts (1995). While these authors focused on different regions, they have found NKPC models with survey expectations to be theoretically consistent. Furthermore, based on the models with the output gap and survey expectations, Calvo probability for the Baltic states was estimated to range between 0.72 and 0.78. These values are close to the Calvo probability of 0.75 proposed by Smets and Wouters (2003) as the baseline for the euro area.

For the basic closed economy models, some patterns can be observed regarding the slope of the NKPC. In most models, marginal cost proxies are statistically insignificant in the ‘postcrisis’ sample, while they are statistically significant in the ‘crisis’ sample. Furthermore, the marginal cost coefficients in the ‘postcrisis’ sample generally have lower absolute value. For Latvia, this pattern is consistently observed irrespective of the proxy choice. For Lithuania, same pattern is

observed in some models with the output gap and unemployment gap. For Estonia however, evidence of NKPC flattening is observed only in models with the output gap. In models with the unemployment gap and labor share gap steepening of the NKPC is observed instead. The latter results for Estonia are partially in line with Bulligan and Vivano (2017), who have observed steepening of the NKPC in some of the European countries after the financial crisis of 2008. Based on these results, the first hypotheses, which states: “For the Baltic states marginal costs have lower impact on the inflation rate after the financial crisis of 2008” cannot generally be rejected for Latvia and Lithuania. Same hypothesis, however, is rejected for Estonia, due to evidence of steepening of the NKPC.

The estimation results for the hybrid NKPC models (see section 3.2.) are shown to generally be theoretically inconsistent. This is in line with Mihailov *et al.* (2011a), who have found the hybrid models to be theoretically inconsistent for most of the Baltic states. Results are also partially in line with Zobl and Ertl (2020), who have found hybrid NKPC models to have worse empirical performance compared to the basic models for the CEE region. However, Zobl and Ertl (2020) focused on the open economy models.

Despite being theoretically inconsistent, some of the estimated hybrid NKPC models have statistically significant backwards- and forward-looking inflation expectations. These results are partially in line with Vašíček (2010) and Mihailov *et al.* (2011a), who found both types of inflation expectations to be statistically significant in the hybrid models for the Baltic states, despite models themselves being theoretically inconsistent. Estimation results (see section 3.2.) reveal forward-looking inflation expectations to consistently have higher weights for Estonia, which is in line with Dabušinskas and Kulikov (2007) and Mihailov *et al.* (2011a). For Latvia evidence is mixed. However, forward-looking inflation expectations seem to generally have higher weight. For Lithuania, both types of inflation expectations are statistically significant only in one model, in which forward-looking expectations have higher weight. As a result, the second hypothesis: “for the Baltic states, forward-looking inflation expectations have higher impact on the inflation rate compared to the backwards-looking inflation expectations” cannot be rejected for Estonia and Lithuania. Same hypothesis cannot generally be rejected for Latvia.

Similar to the hybrid NKPC models, open economy models generally yield no theoretically consistent results for chosen subsamples. However, as was shown in the closed economy models,

results are generally theoretically consistent for the full sample, which was not used in the estimation of the open economy models.

Nevertheless, a pattern of statistical significance for the external variables can be observed. Change in the REER is statistically significant only for Latvia and Lithuania, depending on the choice of the marginal cost proxy. Which is contrary to Vašíček (2010), who found it to be statistically insignificant for all the Baltic states. Change in the commodity prices for Latvia is statistically significant for the ‘crisis’ sample irrespective of the marginal cost proxy. For Estonia same external factor is statistically significant for the ‘postcrisis’ sample for models with the output gap and the labor share gap. For Lithuania, same external factor is statistically significant only for the ‘postcrisis’ sample for models with the unemployment gap. These results are partially in line with Mihailov *et al.* (2011a), who found external factors to be statistically significant and correctly signed, despite other parts of the NKPC models being theoretically inconsistent. Based on these results, third hypothesis: “For the Baltic states external factors are consistent with the small open economy NKPC theory” cannot be rejected for any of the Baltic states. However, results depend on the choice of the external factor proxy.

To conclude, estimation results show that closed economy models with some combinations of marginal cost and inflation expectations proxies are theoretically consistent. While these results support the NKPC theory, they might be detached from reality. It would be unrealistic to assume the Baltic states to be closed economies. When Baltic states are assumed to be open economies, models become generally theoretically inconsistent. However, the fact that external factor is generally correctly signed and statistically significant indicates that domestic inflation of the Baltic states is in fact affected by the factors outside of the domestic market. Hence, for the Baltic states further adjustment and rethinking of the NKPC microfoundation might be required to account for the open economy, as simple addition of the external factor into the models does not yield satisfactory results.

CONCLUSION

The aim of the thesis was to estimate NKPC models for the Baltic states that would be in line with the NKPC theory. Based on the empirical estimation results the aim of the thesis is partially achieved. The estimation results for the basic closed economy models are theoretically consistent for all the Baltic states. However, combinations of proxies and samples that yield those models vary per state. On the other hand, when models are extended to feature open economy external factors or lagged inflation, results are generally not in line with the NKPC theory. Nevertheless, some patterns can be observed in those models, which allow to analyze the stated hypotheses.

Applying estimation results to test the hypotheses yields following results. First hypothesis, which states: “For the Baltic states marginal costs have lower impact on the inflation rate after the financial crisis of 2008” cannot generally be rejected for Latvia and Lithuania. This is because, flattening of the NKPC curve is observed for those states based on the basic closed economy models. For Estonia, hypothesis is rejected, due to evidence the NKPC slope becoming steeper.

Second hypothesis states: “For the Baltic states, forward-looking inflation expectations have higher impact on the inflation rate compared to the backwards-looking inflation expectations”. It cannot be rejected for Estonia and Lithuania. For Latvia hypothesis cannot generally be rejected. While there is evidence of both types of inflation expectations having higher weight for Latvia. Forward-looking inflation expectations seem to be dominant.

Third and final hypothesis states: “For the Baltic states external factors are consistent with the small open economy NKPC theory”. It cannot be rejected for any of the Baltic states. For Latvia and Lithuania both external factors are consistently correctly signed and statistically significant. However, for Estonia only change in the all commodity price index is statistically significant and correctly signed.

Empirical results are generally in line with previous empirical literature. Similar patterns of hybrid and open economy models being theoretically inconsistent were previously observed for the Baltic states. Theoretical inconsistency of the hybrid models was also observed more recently for the neighboring region.

In line with the stated aim of the thesis, to test different combinations of proxies and NKPC specifications, approximately 500 models were estimated. This, in turn, made comparison of results between different combinations and states more complex. However, achieved results illustrate that performance of the NKPC models for the Baltic states heavily depends on the choice of both marginal cost and inflation expectations proxies. Hence, if less models were estimated, results may have been biased. Results, also show some heterogeneity between the Baltic states.

One potential problem regarding the estimation results is the presence of autocorrelation and weak instruments in some of the theoretically consistent models. However, attempt to address the issue using alternative estimation methods proved to be unsuccessful, as results seem to indicate poor fit of CUE GMM models to data.

Future research on the topic of the NKPC for the Baltic states should focus on one country. This would decrease the number of models required to be estimated. Furthermore, different sets of instruments should be tested within one regression method to address the potential weak instruments. Focusing on one country would also allow to analyze why some marginal cost proxies are more in line with the NKPC theory than the others for the particular country, as this question was not addressed in the thesis.

Another approach for the future would be to estimate the whole New Keynesian framework, which would include the NKPC, the dynamic New Keynesian IS curve and some monetary policy rule. However, because Baltic states are part of the euro area, their monetary policies are not independent. Hence, microfoundation of the New Keynesian framework would have to be extended to account for that.

KOKKUVÕTTE

UUSKEINSLIKE PHILLIPSI KÕVERATE HINDAMINE BALTI RIIKIDES

Daniil Hamidullin

Traditsiooniline Phillipsi kõver väljendab negatiivset empiirilist seost inflatsiooni ja töötuse määra vahel, mis oli dokumenteeritud Phillipsi (1958) poolt. Phillipsi kõvera peamiseks puuduseks on aga teoreetilise tausta puudumine. Alternatiivina, teoreetiliselt põhjendatud uuskeinslik Phillipsi kõver (*New Keynesian Phillips Curve*, edasiselt NKPC) ilmus uuskeinsliku raamistiku osana 1980. aastatel (Mavroeidis *et al.* 2014).

NKPC teoreetiline taust tuleneb mikromajanduslikest aspektidest ja mudel eeldab, et majandus koosneb monopolistlikult konkureerivatest firmadest ja (kodu)majapidamistest. Lisaks, eeldatakse, et nii leibkonnad kui ka ettevõtted käituvad ratsionaalselt ja maksimeerivad oma kasumit või heaolu. Heaolu (kasulikkuse) maksimeerimiseks minimeerivad majapidamised oma tarbimiskulutusi, mis omaltpoolt mõjutab nõudlust. Nõudlust turgudel on kasutakse firmade poolt kasumite maksimeerimiseks. Samal ajal, valivad firmad oma toodete hinnad eeldusel, et hinnad jäävad fikseerituks mingiks ajaks. (Walsh 2010) Majapidamiste ja firmade koostoimimise tulemus tekitab NKPC mudelis seosed, mille kohaselt praegune inflatsiooni määr on positiivselt mõjutatud majandusaktiivsuse ja firmade inflatsiooni ootuste poolt. Vaatamata teoreetilise tausta olemasolule ei ole NKPC mudelite empiiriliste hinnangute tulemused olnud üksmeelsed.

See võib-olla seotud asjaoluga, et selliseid näitajaid nagu reaalne majandus aktiivsus ja inflatsiooni ootused on raske mõõta. Seetõttu on kasutatud asendajaid (*proxies*). Asendajate valik aga võib mõjutada empiiriliste hinnangute tulemusi. Lisaks sellele, on NKPC mudeleid laiendatud teiste autorite poolt. Näiteks, Galí ja Gertler (1999) on lisanud mudelisse viivitusega inflatsiooni määra (*lagged inflation*). Galí ja Monacelli (2005) on toonud mudelisse välismõjud, et muuta majandus suletust avatuks. NKPC empiiriline kehtivus on potentsiaalselt mõjutatud ka 2008. aasta finantskriisist. Pärast kriisi inflatsiooni ja majandusaktiivsuse vaheline seos võib-olla

muutunud nõrgemaks *i.e.* NKPC tõus võib-olla muutunud lamedamaks. Seega lõputöö uurimisprobleem on NKPC mudelite empiiriline mittevastavus NKPC teoreetilistele mudelitele.

Lõputöö eesmärgiks on empiiriliselt hinnata NKPC mudeleid, mis oleksid kooskõlas NKPC teooriaga. Eesmärgi saavutamiseks on esitatud kolm hüpoteesi, mis põhinevad varasemate empiiriliste tööde tulemustel. Hüpoteesid on sõnastatud hiljem, koos tulemuste aruteluga.

Kooskõlas varasema empiirilise kirjandusega mudelite hindamiseks on kasutatud *Generalized Method of Moments* (GMM). Esmaselt, *Two-Stage Least Squares* (2SLS) meetod on kasutatud, mis on GMM erijuhtum. Pidevalt uuendatud (*continuously updated*) GMM (edasisealt CUE GMM) versioon on kasutatud aga alternatiivina (vaata Zobl ja Ertl 2020).

Töös on analüüsitud kvartaalseid andmeid Balti riikide kohta, mis hõlmavad perioodi 2002Q2 kuni 2019Q4. Perioodi valik on põhjendatud andmete kättesaadavusega. Aasta 2020 on eemaldatud andmetest koronaviiruse pandeemia tõttu. Pandeemia on avaldanud mõju nii Balti riikide kui ka maailma majandusele, mida on terviklikult veel raske hinnata. Seega, pandeemia tingimustest teostatud vaatlused võivad olla ekstreemsed (*outliers*). Regiooni valik on seotud sellega, et varasem empiiriline kirjandus (vaata Mihailov *et al.* 2011a; Vašiček 2010) kõnesoleva regiooni kohta on vananenud. Lisaks sellele, potentsiaalset NKPC kalde lamedamaks muutumist ei ole antud regioonis uuritud.

Andmed on peamiselt pärit Eurostat andmebaasist. Inflatsiooni määra on kasutatud sõltuva muutujana kõikides mudelites. Majandus aktiivsuse asendajatena on kasutatud SKP lõhet, töötajate hüvitiste lõhe parameetrit (*labor share gap*) ja töötusemäära lõhet. Inflatsiooni ootuste asendajatena on kasutatud andmeid Euroopa komisjoni tarbijate inflatsiooni ootuste küsitlusest (edasisealt küsitluse ootused) ja inflatsiooni väärtuseid järgmisest perioodist (*leaded infaltion*). Välismõju asendajana on kasutatud reaalselt efektiivset vahetuskurssi (REER) Eurostatist ja maailma toormehindade (*all commodity prices*) muutust Rahvusvahelisest Valuutafondist (IMF). NKPC tõusu muutuse uurimiseks on kasutatud all-valimeid. Allvalim üks hõlmab perioodi 2002Q2 kuni 2010Q4, allvalim kaks hõlmab perioodi 2010Q4 kuni 2019Q4.

Lõputöö eesmärk on empiiriliste mudelite hindamise tulemusena saavutatud. Üks osa hinnatud põhilistest suletud majanduse mudelitest on NKPC teooriaga kooskõlas. Parimad tulemused on saavutatud, kui SKP lõhe ja töötajate hüvitiste lõhe on kasutatud koos küsitluse ootustega.

Hübriidsed ja avatud majandusega mudelid ei ole NKPC teoriaga üldiselt kooskõlas. Kuid nende mudelite tulemused võimaldavad arutleda püstitatud hüpoteeside kehtivuse üle. Saadud tulemused on üldjuhul varasema empiirilise kirjandusega kooskõlas.

Hüpotees 1: „Balti riikide jaoks on NKPC tõus muutunud lamedamaks pärast 2008. aasta finantskriisi” on kinnitatud Läti ja Leedu jaoks. Eesti jaoks on hüpotees tagasi lükatud. See on seotud sellega, et Eesti jaoks on NKPC tõus üldiselt muutunud järsemaks.

Hüpotees 2: „Balti riikide jaoks, ennetavad (*forward-looking*) inflatsiooni ootused on kõrgema osakaaluga võrreldes viivitusega (*backwards-looking*) inflatsiooni ootustega“ on kinnitatud Eesti ja Leedu jaoks. Läti jaoks on hüpotees ainult osaliselt kinnitatud.

Hüpotees 3: „Balti riikide jaoks on välismõjud kooskõlas avatud majanduse NKPC teoriaga“ on kinnitatud kõigi Balti riikide jaoks. Vaatamata sellele, et avatud majandusega NKPC mudelid üldiselt ei ole kooskõlas teoriaga, on välismõjud olnud statistiliselt olulised ja positiivsete koefitsientide väärtustega.

Alternatiivse hindamis meetodi kasutamine ei olnud tulemuslik. Saadud mudelid on näidanud kõrget negatiivset R-ruut väärtust, mis viitab nende ebasobivusele antud andmete osas. See võib-olla seotud valitud instrumentide ja suhteliselt väikese vaatluste arvuga.

Tuleviku uuringute suund võiks olla fookusega NKPC mudelite analüüsimisele ühe Balti riigi raames. See vähendaks mudelite arvu, mis omaltpoolt muudaks analüüsi lihtsamaks. Lisaks võib-olla käesoleva lõputöö edasiarendamise viisiks kogu uuskeinsliku süsteemi hindamine. See aga vajaks Dynamic Stochastic General Equilibrium (DSGE) mudelite kasutamist. Lisaks sellele, vajaks Baltiriikide jaoks Uuskeinsliku mudel muutmist. See on seotud sellega, et kõnesoleva mudeli teooria eeldab, et riikidel on oma sõltumatu monetaarpoliitika. Balti riigid on aga eurotsooni liikmed ning seetõttu on nende monetaarpoliitika ühendatud teiste liikmesriikidega.

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APPENDICES

Appendix 1. Approximation of the optimal price choice equation

Equation 1.11, can be rewritten into the following:

$$\left(\frac{p_t^*}{P_t}\right) \left[E_t \sum_{i=0}^{\infty} \omega^i \beta^i C_{t+i}^{1-\sigma} \left(\frac{P_{t+i}}{P_t}\right)^{\theta-1} \right] = \left(\frac{\theta}{\theta-1}\right) \left[E_t \sum_{i=0}^{\infty} \omega^i \beta^i C_{t+i}^{1-\sigma} \varphi_{t+i} \left(\frac{P_{t+i}}{P_t}\right)^{\theta} \right]$$

In the given equation $\left(\frac{p_t^*}{P_t}\right)$ can be replaced with Q_t . $\left(\frac{\theta}{\theta-1}\right)$ can be replaced with μ . This yield:

$$Q_t \left[E_t \sum_{i=0}^{\infty} \omega^i \beta^i C_{t+i}^{1-\sigma} \left(\frac{P_{t+i}}{P_t}\right)^{\theta-1} \right] = \mu \left[E_t \sum_{i=0}^{\infty} \omega^i \beta^i C_{t+i}^{1-\sigma} \varphi_{t+i} \left(\frac{P_{t+i}}{P_t}\right)^{\theta} \right]$$

Left and right sides of given equation can be approximated separately as follows.

The left-hand side approximation:

$$\left(\frac{C^{1-\sigma}}{1-\omega\beta}\right) + \left(\frac{C^{1-\sigma}}{1-\omega\beta}\right) \hat{q}_t + C^{1-\sigma} \sum_{i=0}^{\infty} \omega^i \beta^i [(1-\sigma)E_t \hat{c}_{t+i} + (\theta-1)(E_t \hat{p}_{t+i} - \hat{p}_t)]$$

The right-hand side approximation:

$$\mu \left\{ \left(\frac{C^{1-\sigma}}{1-\omega\beta}\right) \varphi + \varphi C^{1-\sigma} \sum_{i=0}^{\infty} \omega^i \beta^i [E_t \hat{\varphi}_{t+i} + (1-\sigma)E_t \hat{c}_{t+i} + \theta(E_t \hat{p}_{t+i} - \hat{p}_t)] \right\}$$

Setting left and right side to be equal and considering that $\mu\varphi = 1$ returns allows to cancel repeating terms. This yield:

$$\begin{aligned} \left(\frac{C^{1-\sigma}}{1-\omega\beta}\right)\hat{q}_t + C^{1-\sigma}\sum_{i=0}^{\infty}\omega^i\beta^i[(1-\sigma)E_t\hat{c}_{t+i} + (\theta-1)(E_t\hat{p}_{t+i} - \hat{p}_t)] \\ = C^{1-\sigma}\sum_{i=0}^{\infty}\omega^i\beta^i[E_t\hat{\varphi}_{t+i} + (1-\sigma)E_t\hat{c}_{t+i} + \theta(E_t\hat{p}_{t+i} - \hat{p}_t)] \end{aligned}$$

Appendix 5 continues

Dividing both sides of the equation by $C^{1-\sigma}$ yields:

$$\begin{aligned} \left(\frac{1}{1-\omega\beta}\right)\hat{q}_t + \sum_{i=0}^{\infty}\omega^i\beta^i[(1-\sigma)E_t\hat{c}_{t+i} + (\theta-1)(E_t\hat{p}_{t+i} - \hat{p}_t)] \\ = \sum_{i=0}^{\infty}\omega^i\beta^i[E_t\hat{\varphi}_{t+i} + (1-\sigma)E_t\hat{c}_{t+i} + \theta(E_t\hat{p}_{t+i} - \hat{p}_t)] \end{aligned}$$

Further cancelling repeating terms returns:

$$\left(\frac{1}{1-\omega\beta}\right)\hat{q}_t = \sum_{i=0}^{\infty}\omega^i\beta^i[E_t\hat{\varphi}_{t+i} + E_t\hat{p}_{t+i} - \hat{p}_t]$$

This equation can be rewritten as:

$$\left(\frac{1}{1-\omega\beta}\right)\hat{q}_t = \sum_{i=0}^{\infty}\omega^i\beta^i[E_t\hat{\varphi}_{t+i} + E_t\hat{p}_{t+i}] - \left(\frac{1}{1-\omega\beta}\right)\hat{p}_t$$

Dividing both sides by $\left(\frac{1}{1-\omega\beta}\right)$ and adding \hat{p}_t returns:

$$\hat{p}_t + \hat{q}_t = (1-\omega\beta)\sum_{i=0}^{\infty}\omega^i\beta^i[E_t\hat{q}_{t+i} + E_t\hat{p}_{t+i}]$$

Which gives equation 1.15. This equation can further be rearranged into the following form:

$$\hat{q}_t + \hat{p}_t = (1 - \omega\beta)(\hat{\varphi}_t + \hat{p}_t) + \omega\beta(E_t q_{t+1} + E_t \hat{p}_{t+1})$$

Moving \hat{p}_t to the right-side yields:

$$\hat{q}_t = (1 - \omega\beta)(\hat{\varphi}_t + \hat{p}_t) + \omega\beta(E_t \hat{q}_{t+1} + E_t \hat{p}_{t+1}) - \hat{p}_t$$

$$\hat{q}_t = (1 - \omega\beta)\hat{\varphi}_t + (1 - \omega\beta)\hat{p}_t + \omega\beta(E_t \hat{q}_{t+1} + E_t \hat{p}_{t+1}) - \hat{p}_t$$

$$\hat{q}_t = (1 - \omega\beta)\hat{\varphi}_t + \hat{p}_t - \omega\beta\hat{p}_t + \omega\beta(E_t \hat{q}_{t+1} + E_t \hat{p}_{t+1}) - \hat{p}_t$$

$$\hat{q}_t = (1 - \omega\beta)\hat{\varphi}_t + \omega\beta(E_t \hat{q}_{t+1} + E_t \hat{p}_{t+1} - \hat{p}_t)$$

Rearranging the last equation yields:

$$\hat{q}_t = (1 - \omega\beta)\hat{\varphi}_t + \omega\beta(E_t \hat{q}_{t+1} + E_t \pi_{t+1}), \quad \pi_{t+1} = E_t \hat{p}_{t+1} - \hat{p}_t$$

Which is the equation 1.16 of the thesis.

Appendix 2. Derivation of the output gap as a proxy for the marginal cost

From equation 1.9 it is known that firms' marginal cost φ_{jt} equals real wage divided by the aggregate productivity disturbance:

$$\varphi_{jt} = \frac{W_t/P_t}{Z_t}$$

At the same time, in flexible price setting all the firms would set the same price. Following:

$\left(\frac{p_t^*}{P_t}\right) = \mu\varphi_t, \mu = \left(\frac{\theta}{\theta-1}\right)$ it means that marginal cost would be at its steady state value, which is $1/\mu$. Unlike prices, nominal wages are assumed to be flexible. Hence real wage must equal the rate of substitution between work and leisure:

$$\frac{\chi N_t^\eta}{C_t^{-\sigma}} = \frac{W_t}{P_t}$$

This condition can be rewritten in terms of the percentage deviation from the steady state, which yields:

$$\hat{\omega}_t - \hat{p}_t = \eta\hat{n}_t + \sigma\hat{y}_t$$

where

$\hat{\omega}_t$ – real wage deviation from the steady-state,

\hat{n}_t – time working deviation from the steady-state,

\hat{p}_t – price deviation from the steady-state,

\hat{y}_t – output deviation from the steady state under the fixed prices.

Two conditions like those used in the appendix 4 but expressed in terms of deviation from the steady state, can be stated. First, consumption deviation from the steady-state equals output deviation from the steady state: $\hat{c}_t = \hat{y}_t$. Second, output deviation from the steady state equals sum of time spent working and aggregate productivity disturbance deviations from the steady-state: $\hat{n}_t = \hat{y}_t - \hat{z}_t$. Substituting stated conditions into the previous equation yields:

$$\hat{\varphi}_t = (\sigma + \eta) \left[\hat{y}_t - \left(\frac{1 + \eta}{\sigma + \eta} \right) \hat{z}_t \right]$$

Linearizing last equation from appendix 4, which corresponds to production under the flexible-prices regime yields:

$$\hat{y}_t^f = \left(\frac{1 + \eta}{\sigma + \eta} \right) \hat{z}_t$$

Replacing $\left(\frac{1 + \eta}{\sigma + \eta} \right) \hat{z}_t$ with \hat{y}_t^f yields:

$$\hat{\phi}_t = \gamma(\hat{y}_t - \hat{y}_t^f), \quad \gamma = (\sigma + \eta)$$

Appendix 3. Expanded summary statistics table

		Inflation rate, %	Labor gap, log	Output gap, log	Unemployment gap, log	Survey expectations, %	Change in REER, %	Change in commodity index, %
EE	Mean	0.806	-0.094	0.241	-1.521	0.722	0.456	1.057
	Median	0.793	-0.783	0.080	-2.573	0.600	0.472	0.999
	Maximum	3.649	8.628	9.652	60.666	1.671	2.796	14.809
	Minimum	-1.385	-4.491	-11.033	-66.712	0.214	-2.755	-23.168
	Std.Dev.	0.833	3.010	4.275	24.044	0.415	1.148	6.424
	Skewness	0.458	1.237	-0.105	-0.062	0.680	-0.357	-0.794
	Kurtosis	4.770	4.186	3.940	4.059	2.223	3.080	4.824
LV	Mean	0.911	-0.293	0.263	-0.813	0.794	0.217	1.377
	Median	0.705	-0.414	0.239	0.115	0.329	0.230	1.133
	Maximum	4.712	13.909	12.637	43.546	2.343	7.249	14.953
	Minimum	-1.083	-7.164	-9.958	-57.112	0.059	-3.586	-23.089
	Std.Dev	1.142	4.057	4.784	19.876	0.751	1.733	6.410
	Skewness	1.097	1.245	0.312	-0.174	0.859	0.858	-0.844
	Kurtosis	4.937	5.227	4.030	3.723	2.109	5.950	4.834
LT	Mean	0.634	-0.161	0.232	-1.659	0.662	0.291	1.045
	Median	0.547	-0.416	0.262	-1.636	0.459	0.230	1.115
	Maximum	3.348	6.851	10.071	44.483	1.730	7.995	14.934
	Minimum	-1.242	-4.741	-8.492	-61.468	0.063	-4.724	-23.154
	Std.Dev	0.867	2.569	3.804	22.143	0.466	1.737	6.407
	Skewness	0.907	0.789	0.321	-0.481	0.834	1.149	-0.800
	Kurtosis	4.568	3.227	4.317	3.957	2.469	8.020	4.857

Source: Eurostat (2021a, 2021b, 2021c, 2021d, 2021e), European Commission (2021), International Monetary Fund (2021); author's calculations

Notes: Std.Dev is the standard deviation.

Appendix 5. Stationarity test results for the ‘crisis’ sample

	Test	Inflation	Output gap	Labor share gap	Unemp. gap	Survey expectations	REER	Commodity index
EE	ADF (Intercept)	-2.711 (0.083)	-1.146 (0.686)	-3.820 (0.007)	-2.823 (0.066)	-1.615 (0.464)	-4.254 (0.002)	-3.710 (0.008)
	ADF (Trend and int.)	-2.748 (0.225)	-1.237 (0.886)	-4.330 (0.010)	-2.802 (0.207)	-1.811 (0.677)	-4.175 (0.012)	-3.665 (0.039)
	ADF (None)	-1.744 (0.077)	-1.163 (0.218)	-3.941 (0.000)	-2.804 (0.007)	-0.538 (0.477)	-3.810 (0.000)	-3.476 (0.001)
	KPSS (Intercept)	0.126	0.162	0.246	0.149	0.209	0.127	0.084
	KPSS (Trend and int.)	0.095	0.147	0.095	0.139	0.151	0.099	0.085
LV	ADF (Intercept)	-1.891 (0.332)	-2.770 (0.074)	-2.196 (0.212)	-1.631 (0.456)	-1.027 (0.732)	-3.645 (0.010)	-3.631 (0.010)
	ADF (Trend and int.)	-1.888 (0.639)	-1.266 (0.879)	-3.761 (0.033)	-1.603 (0.770)	-1.492 (0.813)	-3.584 (0.046)	-3.546 (0.050)
	ADF (None)	-1.128 (0.231)	-2.776 (0.007)	-2.200 (0.029)	-1.671 (0.089)	-0.443 (0.515)	-3.633 (0.001)	-3.277 (0.002)
	KPSS (Intercept)	0.132	0.137	0.407	0.143	0.198	0.203	0.107
	KPSS (Trend and int.)	0.132	0.138	0.089	0.140	0.189	0.154	0.086
LT	ADF (Intercept)	-2.509 (0.122)	-1.335 (0.602)	-2.391 (0.152)	-2.417 (0.145)	-1.697 (0.424)	-5.039 (0.000)	-3.677 (0.009)
	ADF (Trend and int.)	-2.438 (0.355)	-1.411 (0.840)	-1.941 (0.611)	-2.359 (0.393)	-0.404 (0.983)	-4.959 (0.002)	-3.634 (0.042)
	ADF (None)	-1.675 (0.088)	-1.362 (0.157)	-2.318 (0.022)	-2.428 (0.017)	0.032 (0.686)	-4.955 (0.000)	-3.445 (0.001)
	KPSS (Intercept)	0.305	0.137	0.441	0.149	0.371	0.093	0.087
	KPSS (Trend and int.)	0.135	0.132	0.087	0.147	0.171	0.095	0.087

Source: Eurostat (2021a, 2021b, 2021c, 2021d, 2021e), European Commission (2021), International Monetary Fund (2021); author’s calculations

Notes:

1. Unemployment gap is the unemp. gap; real effective exchange rate is the REER; int. is intercept.
2. P-values for the ADF tests are given in parentheses under the test statistic values.
3. Critical values (1%; 5%; 10%) for the KPSS (Intercept) are 0.739; 0.463; 0.347.
4. Critical values (1%; 5%; 10%) for the KPSS (Trend and intercept) are 0.216; 0.146; 0.119.

Appendix 6. Stationarity test results for the ‘postcrisis’ sample

	Test	Inflation	Output gap	Labor share gap	Unemp. gap	Survey expectations	REER	Commodity index
EE	ADF (Intercept)	-1.940 (0.311)	-3.934 (0.004)	-3.899 (0.005)	-3.953 (0.004)	-3.135 (0.033)	-6.930 (0.000)	-4.929 (0.000)
	ADF (Trend and int.)	-2.011 (0.577)	-3.614 (0.042)	-4.602 (0.004)	-3.526 (0.051)	-2.475 (0.338)	-6.829 (0.000)	-4.880 (0.002)
	ADF (None)	-1.439 (0.138)	-3.554 (0.001)	-3.574 (0.001)	-3.597 (0.001)	-2.936 (0.005)	-6.192 (0.000)	-4.999 (0.000)
	KPSS (Intercept)	0.217	0.269	0.420	0.301	0.343	0.046	0.149
	KPSS (Trend and int.)	0.164	0.129	0.170	0.114	0.163	0.047	0.151
LV	ADF (Intercept)	-3.438 (0.016)	-5.180 (0.000)	-4.551 (0.001)	-3.265 (0.024)	-2.453 (0.135)	-7.407 (0.000)	-4.918 (0.000)
	ADF (Trend and int.)	-3.388 (0.069)	-4.250 (0.009)	-5.292 (0.001)	-2.939 (0.163)	-2.482 (0.335)	-7.334 (0.000)	-4.867 (0.002)
	ADF (None)	-2.650 (0.010)	-5.044 (0.000)	-4.551 (0.001)	-3.152 (0.003)	-1.181 (0.213)	-7.289 (0.000)	-4.988 (0.000)
	KPSS (Intercept)	0.158	0.490	0.385	0.331	0.258	0.090	0.176
	KPSS (Trend and int.)	0.157	0.115	0.155	0.129	0.188	0.064	0.150
LT	ADF (Intercept)	-2.345 (0.164)	-5.803 (0.000)	-1.916 (0.322)	-4.669 (0.001)	-5.672 (0.000)	-7.231 (0.000)	-4.936 (0.000)
	ADF (Trend and int.)	-2.311 (0.418)	-5.029 (0.001)	-2.071 (0.545)	-3.598 (0.044)	-4.588 (0.004)	-7.134 (0.000)	-4.884 (0.002)
	ADF (None)	-1.640 (0.095)	-4.535 (0.000)	-1.785 (0.071)	-4.108 (0.000)	-2.577 (0.011)	-7.150 (0.000)	-5.006 (0.000)
	KPSS (Intercept)	0.157	0.333	0.342	0.647	0.360	0.068	0.173
	KPSS (Trend and int.)	0.159	0.118	0.146	0.160	0.185	0.059	0.149

Source: Eurostat (2021a, 2021b, 2021c, 2021d, 2021e), European Commission (2021), International Monetary Fund (2021); author’s calculations

Notes:

1. Unemployment gap is the unemp. gap; real effective exchange rate is the REER; int. is intercept.
2. P-values for the ADF tests are given in parentheses under the test statistic values.
3. Critical values (1%; 5%; 10%) for the KPSS (Intercept) are 0.739; 0.463; 0.347.
4. Critical values (1%; 5%; 10%) for the KPSS (Trend and intercept) are 0.216; 0.146; 0.119.

Appendix 7. Basic NKPC with output gap and led inflation, subsamples

	Estonia		Latvia		Lithuania	
	Crisis	Postcrisis	Crisis	Postcrisis	Crisis	Postcrisis
Constant	0.706** (0.309)	0.259 (0.173)	0.869** (0.317)	0.051 (0.204)	-0.056 (0.467)	0.217 (0.182)
Output gap	0.084** (0.032)	0.006 (0.077)	0.105*** (0.034)	0.004 (0.059)	0.034 (0.062)	-0.060 (0.095)
Leaded inflation	0.358 (0.240)	0.654*** (0.241)	0.411** (0.189)	0.915** (0.444)	0.981** (0.434)	0.576* (0.324)
Observations	32	37	32	37	32	37
R-squared	0.495	0.034	0.772	0.071	0.367	0.094
Durbin-Watson	1.946	2.909	1.382	2.761	2.277	2.760
Hansen J-statistic	7.715***	9.668***	12.510**	5.143***	3.475***	6.369***
Weak instrument (Cragg-Donald F)	2.907	3.493	3.250	0.734	1.408	1.612

Source: Eurostat (2021a, 2021b); author's calculations

Notes:

1. Standard errors are given in parentheses.
2. For the variables *, **, *** signifies statistical significance at 10%, 5%, 1% respectively.
3. For weak instrument test critical values are 18.30, 10.43, and 6.22 for 5%, 10%, and 20% thresholds, respectively.

Appendix 8. Basic NKPC with output gap and survey expectations, no constant

	Estonia			Latvia			Lithuania		
	Crisis	Postcrisis	Full	Crisis	Postcrisis	Full	Crisis	Postcrisis	Full
Output gap	0.067*** (0.024)	-0.026 (0.055)	0.068*** (0.019)	0.084*** (0.023)	-0.014 (0.032)	0.070*** (0.018)	0.108*** (0.025)	-0.077 (0.061)	0.097*** (0.021)
Survey expectations	1.033*** (0.125)	1.586 (0.160)	1.093*** (0.093)	1.018*** (0.100)	1.781*** (0.230)	1.072*** (0.078)	0.909*** (0.117)	1.211 (0.170)	0.966*** (0.091)
Observations	32	37	72	32	37	72	32	37	72
R-squared	0.496	0.470	0.501	0.693	0.391	0.708	0.577	0.315	0.531
Durbin-Watson	1.149	1.975	1.372	0.730	1.551	0.841	1.511	1.777	1.471
Hansen J-statistic	8.740***	8.876***	13.924***	13.614**	5.545***	23.973***	6.700***	8.379***	9.746
Weak instrument (Cragg-Donald F)	16.264	10.492	34.874	47.694	32.941	75.288	12.233	35.847	26.537

Source: Eurostat (2021a, 2021b), European Commission (2021); author's calculations

Notes:

1. For the variables *, **, *** signifies statistical significance at 10%, 5%, 1% respectively.
2. For Hansen J-statistic *, **, *** signifies acceptance of the null hypothesis at 1%, 5%, 10%.
3. For weak instrument test critical values are 18.30, 10.43, and 6.22 for 5%, 10%, and 20% thresholds, respectively.

Appendix 9. Basic NKPC with leded inflation and labor share gap, Estonia and Lithuania

	Estonia			Lithuania		
	Crisis	Postcrisis	Full	Crisis	Postcrisis	Full
Constant	-0.161 (0.486)	0.359** (0.162)	-0.039 (0.209)	-0.275 (0.324)	0.025 (0.183)	-0.067 (0.167)
Labor share gap	0.056 (0.075)	-0.229** (0.109)	0.019 (0.049)	0.102 (0.068)	-0.031 (0.058)	0.036 (0.045)
Leaded inflation	1.082*** (0.361)	0.160 (0.311)	1.066*** (0.227)	1.098*** (0.250)	0.914*** (0.314)	1.061*** (0.193)
Observations	32	37	72	32	37	72
R-squared	0.280	0.046	0.132	0.386	-0.108	0.260
Durbin-Watson	2.357	2.603	2.693	2.550	3.159	2.655
Hansen J-statistic	9.704***	6.539***	9.020***	4.295***	0.993***	6.305***
Weak instrument (Cragg-Donald F)	1.104	1.127	3.124	1.834	1.800	3.598

Source: Eurostat(2021a, 2021c); author's calculations

Notes:

1. For the variables *, **, *** signifies statistical significance at 10%, 5%, 1% respectively.
2. For Hansen J-statistic *, **, *** signifies acceptance of the null hypothesis at 1%, 5%, 10%.
3. For weak instrument test critical values are 18.30, 10.43, and 6.22 for 5%, 10%, and 20% thresholds, respectively.

Appendix 10. Basic NKPC with survey expectations, labor share gap, Estonia

	Crisis	Postcrisis	Full
Constant	-1.692** (0.762)	-1.294 (0.778)	0.002 (0.170)
Labor share gap	0.091 (0.066)	0.292 (0.254)	-0.065* (0.035)
Survey expectations	2.555*** (0.661)	4.975** (2.226)	1.152*** (0.208)
Observations	32	37	72
R-squared	0.490	0.148	0.397
Durbin-Watson	0.809	1.957	1.286
Hansen J-statistic	12.372**	2.849***	19.450
Weak instrument (Cragg-Donald F)	1.834	0.187	9.085

Source: Eurostat(2021a, 2021c), European Commission (2021); author's calculations

Notes:

1. For the variables *, **, *** signifies statistical significance at 10%, 5%, 1% respectively.
2. For Hansen J-statistic *, **, *** signifies acceptance of the null hypothesis at 1%, 5%, 10%.
3. For weak instrument test critical values are 18.30, 10.43, and 6.22 for 5%, 10%, and 20% thresholds, respectively.

Appendix 11. Basic NKPC with led inflation, unemployment gap, LV, LT

	Latvia			Lithuania		
	Crisis	Postcrisis	Full	Crisis	Postcrisis	Full
Constant	1.084*** (0.391)	0.012 (0.292)	-0.131 (0.165)	0.679 (0.495)	0.360** (0.174)	-0.043 (0.208)
Unemployment gap	-0.030*** (0.010)	-0.004 (0.023)	-0.001 (0.007)	-0.018 (0.012)	0.015 (0.011)	-0.001 (0.007)
Leaded inflation	0.305 (0.231)	1.001 (0.626)	1.145*** (0.151)	0.263 (0.472)	0.272 (0.320)	1.027*** (0.273)
Observations	32	37	72	32	37	72
R-squared	0.771	-0.012	0.601	0.537	0.197	0.293
Durbin-Watson	1.265	2.781	1.890	1.491	2.090	2.639
Hansen J-statistic	10.516***	4.666***	5.511***	7.829***	13.365*	10.785**
Weak instrument (Cragg-Donald F)	1.912	0.366	4.688	0.654	1.161	2.129

Source: Eurostat (2021a, 2021d); author's calculations

Notes:

1. For the variables *, **, *** signifies statistical significance at 10%, 5%, 1% respectively.
2. For Hansen J-statistic *, **, *** signifies acceptance of the null hypothesis at 1%, 5%, 10%.
3. For weak instrument test critical values are 18.30, 10.43, and 6.22 for 5%, 10%, and 20% thresholds, respectively.

Appendix 12. Basic NKPC with survey expectations and unemployment gap, subsamples

	Estonia		Latvia		Lithuania	
	Crisis	Postcrisis	Crisis	Postcrisis	Crisis	Postcrisis
Constant	-0.268 (0.594)	-0.198 (0.283)	1.200* (0.621)	-0.289 (0.240)	-0.036 (0.550)	-0.465 (0.332)
Unemployment gap	-0.010 (0.006)	0.012 (0.010)	-0.036* (0.010)	-0.007 (0.013)	-0.015** (0.007)	-0.013 (0.014)
Survey expectations	1.288** (0.538)	1.978*** (0.599)	0.254 (0.414)	2.738*** (0.846)	0.938* (0.511)	2.249*** (0.760)
Observations	32	37	32	37	32	37
R-squared	0.518	0.575	0.724	0.437	0.587	0.369
Durbin-Watson	1.067	2.363	0.878	1.664	1.165	1.910
Hansen J-statistic	9.332***	4.917***	9.843***	5.366***	6.077***	10.438***
Weak instrument (Cragg-Donald F)	7.913	1.823	5.451	5.144	12.482	5.568

Source: Eurostat (2021a, 2021d), European Commission (2021); author's calculations

Notes:

1. For the variables *, **, *** signifies statistical significance at 10%, 5%, 1% respectively.
2. For Hansen J-statistic *, **, *** signifies acceptance of the null hypothesis at 1%, 5%, 10%.
3. For weak instrument test critical values are 18.30, 10.43, and 6.22 for 5%, 10%, and 20% thresholds, respectively.

Appendix 13. Basic NKPC with survey expectations and unemployment gap, no constant

	Estonia			Latvia			Lithuania		
	Crisis	Postcrisis	Full	Crisis	Postcrisis	Full	Crisis	Postcrisis	Full
Unemployment gap	-0.011** (0.004)	0.017** (0.007)	-0.009** (0.004)	-0.020*** (0.005)	0.006 (0.008)	-0.017*** (0.004)	-0.015*** (0.004)	0.003 (0.008)	-0.013*** (0.003)
Survey expectations	1.052*** (0.121)	1.571*** (0.142)	1.136*** (0.093)	1.033*** (0.096)	1.752*** (0.227)	1.084*** (0.076)	0.905*** (0.117)	1.210*** (0.175)	0.978*** (0.091)
Observations	32	37	72	32	37	72	32	37	72
R-squared	0.517	0.533	0.476	0.702	0.402	0.708	0.585	0.307	0.534
Durbin-Watson	0.691	2.038	0.652	0.727	1.577	0.828	1.167	1.717	1.313
Hansen J-statistic	9.865***	5.063***	16.799*	13.076***	6.614***	23.756	6.280***	11.637***	12.809***
Weak instrument (Cragg-Donald F)	22.834	3.570	18.117	36.829	12.344	60.683	35.106	16.992	60.684

Source: Eurostat (2021a, 2021d), European Commission (2021); author's calculations

Notes:

1. Standard errors are given in parentheses.
2. For the variables *, **, *** signifies statistical significance at 10%, 5%, 1% respectively.
3. For weak instrument test critical values are 18.30, 10.43, and 6.22 for 5%, 10%, and 20% thresholds, respectively.

Appendix 14. Hybrid NKPC with output gap and survey expectations

	Estonia			Latvia			Lithuania		
	Crisis	Postcrisis	Full	Crisis	Postcrisis	Full	Crisis	Postcrisis	Full
Constant	-0.494 (0.826)	-0.636** (0.269)	0.042 (0.159)	0.102 (0.589)	-0.117 (-0.228)	0.025 (0.108)	-0.294 (0.459)	0.414 (0.614)	-0.050 (0.141)
Output gap	0.034 (0.053)	0.083* (0.046)	0.049* (0.025)	0.062 (0.049)	-0.005 (0.095)	0.041* (0.021)	0.089** (0.036)	-0.132 (0.144)	0.086*** (0.026)
Survey expectations	1.347* (0.703)	3.627*** (0.985)	0.764*** (0.270)	0.645* (0.349)	1.399 (0.389)	0.676*** (0.173)	1.156** (0.467)	-1.372 (2.489)	0.948*** (0.258)
Lagged inflation	0.157 (0.276)	-0.557 (0.350)	0.276 (0.208)	0.319 (0.233)	0.403 (1.005)	0.376** (0.156)	0.021 (0.198)	1.339 (1.060)	0.083 (0.186)
Observations	32	37	72	32	37	72	32	37	72
R-squared	0.556	0.521	0.547	0.785	0.402	0.790	0.608	-0.779	0.559
Durbin-Watson	1.318	1.395	2.062	2.518	2.612	2.968	2.734	3.171	2.949
Hansen J-statistic	3.957***	4.015***	9.333**	4.974***	2.462***	6.490***	2.812***	1.300***	5.998***
Weak instrument (Cragg-Donald F)	1.489	1.004	2.430	1.699	0.125	3.976	6.161	0.275	4.179

Source: Eurostat (2021a, 2021b), European Commission (2021); author's calculations

Notes:

1. For the variables *, **, *** signifies statistical significance at 10%, 5%, 1% respectively.
2. For Hansen J-statistic *, **, *** signifies acceptance of the null hypothesis at 1%, 5%, 10%.
3. For weak instrument test critical values are 18.30, 10.43, and 6.22 for 5%, 10%, and 20% thresholds, respectively.

Appendix 15. Hybrid NKPC, survey expectations and unemployment gap, no constant

	Estonia			Latvia			Lithuania		
	Crisis	Postcrisis	Full	Crisis	Postcrisis	Full	Crisis	Postcrisis	Full
Unemployment gap	-0.008 0.006	0.018** 0.007	-0.002 0.004	-0.013** 0.006	0.006 0.008	-0.011** 0.004	-0.013** 0.005	0.003 0.009	-0.013*** 0.004
Survey expectations	0.871*** 0.272	1.889*** 0.516	0.612** 0.263	0.697*** 0.203	1.333* 0.768	0.706*** 0.167	0.740*** 0.226	1.268*** 0.425	0.941*** 0.235
Lagged inflation	0.208 0.260	-0.199 0.310	0.493** 0.224	0.344* 0.183	0.222 0.392	0.365** 0.144	0.189 0.222	-0.048 0.306	0.047 0.219
Observations	32	37	72	32	37	72	32	37	72
R-squared	0.569	0.541	0.504	0.795	0.422	0.792	0.638	0.299	0.549
Durbin-Watson	1.489	1.844	2.429	1.282	2.047	1.516	1.531	1.600	1.408
Hansen J-statistic	6.251***	4.366***	8.850***	3.099***	4.957***	4.640***	1.891***	10.062***	4.432***
Weak instrument (Cragg-Donald F)	1.409	0.844	1.891	2.034	0.667	3.925	1.995	1.402	2.159

Source: Eurostat (2021a, 2021d); author's calculations

Notes:

1. Standard errors are given in parentheses.
2. For the variables *, **, *** signifies statistical significance at 10%, 5%, 1% respectively.
3. For weak instrument test critical values are 18.30, 10.43, and 6.22 for 5%, 10%, and 20% thresholds, respectively.

Appendix 16. Basic open economy NKPC, change in the commodity prices, subsamples

	Estonia		Latvia		Lithuania	
	Crisis	Post crisis	Crisis	Post crisis	Crisis	Post crisis
Labor share gap	0.076*** (0.024)	0.072 (0.067)	0.115*** (0.032)	0.012 (0.034)	0.122*** (0.029)	-0.009 (0.071)
Survey expectations	0.931*** (0.145)	1.397*** (0.170)	0.818*** (0.162)	1.732*** (0.192)	0.822*** (0.140)	1.173*** (0.160)
External factor	0.032 (0.026)	0.073*** (0.033)	0.079* (0.046)	0.026 (0.022)	0.035 (0.028)	0.035 (0.022)
Observations	30	37	30	37	30	37
R-squared	0.555	0.564	0.626	0.607	0.561	0.425
Durbin-Watson statistic	1.323	2.192	0.926	1.449	1.437	1.686
Hansen J-statistic	8.012***	5.685***	7.819***	6.902***	4.719***	7.234***
Weak instrument (Cragg-Donald F)	2.082	0.437	0.808	0.801	1.387	1.569

Source: Eurostat (2021a, 2021c), European Commission (2021), International Monetary Fund (2021); author's calculations

Notes:

1. Standard errors are given in parentheses.
2. External factor is the change in the world commodity index.
3. For the variables *, **, *** signifies statistical significance at 10%, 5%, 1% respectively.
4. For weak instrument test critical values are 18.30, 10.43, and 6.22 for 5%, 10%, and 20% thresholds, respectively.

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